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Photo: *Star Newspaper Service*

Mr. P. D. Baird, Director of the Montreal Office of the Institute from 1947, who has recently resigned and returned to Scotland to take up an appointment at the University of Aberdeen.

PRELIMINARY DATA FROM
SASKATCHEWAN GLACIER, ALBERTA, CANADA[1]

Mark F. Meier*, George P. Rigsby†, and Robert P. Sharp*

A N UNDERSTANDING of glacier flow is not likely to come from field or laboratory studies alone; both are required. Needed from the field are quantitative data on the movement, size, shape, slope, and thickness of flowing ice bodies. Reliable measurements of the amount and absolute direction of movement at points widely distributed over the surfaces of glaciers are sparse. Even the surface velocity map of Hintereisferner (Hess, 1904, p. 136), one of our most thoroughly studied ice streams, shows only the downvalley component of movement. Quantitative data on velocity distribution in depth are even more meagre (Gerrard, Perutz and Roch, 1952; Sharp, 1953), although they are essential to an understanding of the physical properties and behaviour of ice deep within a glacier and to the setting up and interpretation of laboratory experiments. Thickness is known in reasonable detail for a few European valley glaciers (Hess, 1933, p. 43; Renaud and Mercanton, 1948) and along one profile in the Greenland Ice Sheet (Joset, 1950, p. 54), but it has been determined only locally in North American ice bodies (Goldthwait, 1936, pp. 506–7; Poulter, Allen, and Miller, 1949; Littlewood, 1952, p. 124; Allen and Smith, 1953, p. 758; Röthlisberger, 1953, pp. 234–7).

In reaching a satisfactory explanation for the dynamic behaviour of glaciers, the following are a few of the many questions that must be answered. What are the effects in quantitative terms of surface slope, ice thickness, and channel characteristics on flow velocity? What is the influence on velocity of seasonal or other temporal changes in the climatological environment, and what is the exact mechanism by which these changes affect the flow rate? Are variations of velocity within a glacier reasonably uniform in time and space or are they notably heterogeneous and irregular? Do all stream-lines through a cross section accelerate or decelerate in phase, and if not why not? Is there any consistent genetic relation between the mechanics of flow and the various structures visible in glaciers? What orientation patterns do ice crystals in glaciers show, how are these orientations produced, and what relation do they bear to the mechanics of flow? What are the conditions and magnitudes of stress and strain deep within glaciers, and what are the physical properties and behaviours of ice at depth? The present study hopes to provide information bearing on some of these questions.

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Fig. 1. Sketch-map of Saskatchewan Glacier and surroundings.

Fig. 2. Looking west-southwest up Saskatchewan Glacier from Parker Ridge, 11 July 1952. Glacier flows from Columbia Icefield partly obscured by rock spur on right skyline. Mt. Castleguard on centre skyline.

This is a progress report on an active project. The investigations are incomplete, the data obtained have not been fully analysed, and the interpretations offered are necessarily preliminary and tentative. Work on Saskatchewan Glacier was initiated in the summer of 1952 under a grant from the Arctic Institute of North America[1] with equipment provided by the U.S. Office of Naval Research. The work continued in 1953 with Office of Naval Research support, and will be carried further in 1954 on the same basis. The government of Canada graciously granted permission for the field study, and the National Parks Administration of Canada has consistently aided the work. Warden William Black of that organization was especially helpful. The

[1]With funds provided by the U.S. government.

Fig. 1. Sketch-map of Saskatchewan Glacier and surroundings.

following persons have served in field parties, and their assistance is warmly acknowledged: Clarence R. Allen, B. Gunnar Bergman, James E. Conel, Donald B. Emerson, Ben F. Jones, Lee R. Magnolia, Jack W. Rocchio, and Gordon D. Seele. The courteous cooperation of Canadian Customs officials, the privilege of storing equipment in a hut owned by the Alpine Club of Canada, and the loan of two toboggan sleds from the Defence Research Board of Canada are acknowledged with appreciation. The Parsons Survey Company of South Gate, California, kindly supplied without charge an inclinometer for survey of bore holes.

Physical setting

Saskatchewan Glacier flows eastward out of Columbia Icefield which lies astride the British Columbia–Alberta border in the Rocky Mountains at the boundary between Banff and Jasper national parks (52°08N., 117°12W.). The Saskatchewan is a geometrically simple ice stream emerging from the ice field at an altitude of 8,500 feet and flowing a little less than 6 miles through a steep-walled valley to a terminus at 5,900 feet (Fig. 1). Its firn limit is near 8,000 feet. The trunk glacier receives only one tributary which enters from the north at about 8,000 feet altitude. Two former tributaries approach the trunk glacier closely on each side about 2 miles above its terminus but do not attain a junction. The low, gently sloping terminus and a relatively smooth ice surface afford easy access to and movement across the glacier (Fig. 2). Camps were maintained near the Alpine Club hut, one mile below the glacier, and outside the south lateral moraine (Castleguard Camp) 4 miles up the glacier (Fig. 1).

Dimensions of the glacier

The width of Saskatchewan Glacier is a little more than one mile in the Castleguard sector, and it tapers to 0.5 mile near the terminus. The surface slope is about 650 feet per mile as the glacier emerges from the ice field, it is 375 to 400 feet per mile over most of the next 5 miles with some gentler and steeper reaches, and it steepens to 840 feet per mile near the terminus. Transverse profiles across the glacier are relatively flat, except for marginal ablation depressions 75 feet deep.

Seismic reflections obtained by C. R. Allen provide information on ice thickness and configuration of the subglacial floor. A portable 6-trace seismic set was used. The shots, consisting of a small fraction of an ounce of dynamite on an electric cap, were detonated in water-filled holes of 1.5 inches diameter bored 25 to 30 feet into the ice by hand drills, as described elsewhere (Allen and Smith, 1953, pp. 756–7). The shotpoints were arranged along two transverse profiles in the upper reach of the glacier and along a longitudinal profile extending to the terminus (Fig. 3).

The greatest thickness recorded, 1,450 feet, is near the centre-line about 5 miles above the terminus. This is not the maximum, for the subglacial floor here slopes gently upvalley and 15 degrees toward the south wall. The south wall of the valley must be extremely steep for probable thicknesses of 1,050
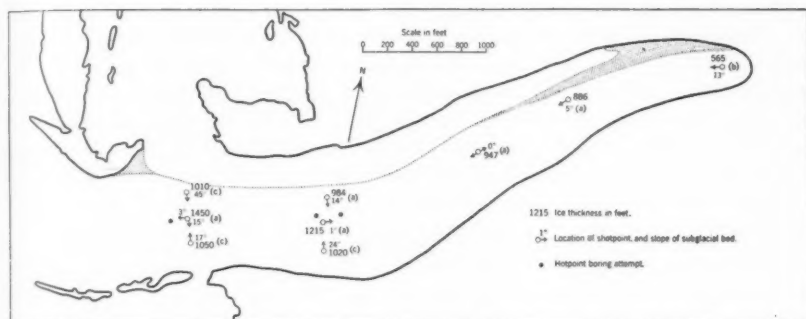
Fig. 3. Map of seismic shotpoints, ice thickness, and slope of subglacial floor, from data obtained by C. R. Allen in 1952: a) good reflection, no doubt about interpretation; b) moderate reflection, some doubt; c) poor reflection, considerable doubt.

and 1,020 feet were recorded within 1,100 feet of the glacier's margin. Thickness decreases progressively along the longitudinal profile toward the terminus, but more slowly than might be expected. A thickness of 565 feet recorded 1,000 feet from the terminus may include some unconsolidated till or other deposits between the ice and the bedrock floor. The flat and, in places, upvalley slope of the bedrock floor at the reflection points along the longitudinal profile affords further testimony to the effectiveness of glacial excavation in overdeepening valleys. After more figures on thickness have been obtained, and the gathering and processing of data on surface slope and velocity have been completed, it may be possible to provide a quantitative evaluation of the relation between surface velocity and ice thickness in this temperate valley glacier.

Observations of surface velocity

Measurements of surface velocity on glaciers usually record only the downvalley component of movement, although it has long been recognized that the motion is not parallel to the surface at most places (Hess, 1933, p. 41). By an excellent bit of deduction, Reid (1896, pp. 917–9) showed that the movement should be obliquely downward in the accumulation area and obliquely upward in the ablation area, and he subsequently confirmed this by actual measurements (1901, p. 750). It follows from flow-lines based on this relation that ice exposed at the surface should be progressively older from the firn limit to the terminus. Reid's deductions have not received the further study they deserve, and observations of absolute direction of motion in glaciers are so few and so scattered as to be more tantalizing than informative (Hess, 1933, p. 41). One objective of the present study is a determination of the amount and absolute direction of motion at many points on the glacier's surface.

When calculations are completed, the movement data from the Saskatchewan should show: (1) the change of velocity along a longitudinal centre-line, thus giving some quantitative measure of compressive flow (Nye, 1952, p. 89),

(2) the actual magnitude of surfaceward movements below the firn limit and the change in angle between the flow vector and the surface along a longitudinal profile, (3) changes of surface velocity in relation to ice thickness, surface slope, and channel cross section, (4) possible convergences or divergences of flow-lines in plan view, (5) velocity differences between individual ice streams within the glacier, (6) variations in winter and summer flow rates in different parts of the ice tongue, and (7) comparative daily velocities at different points on the glacier surface.

Procedure. A total of 52 movement stations has been established on the surface of Saskatchewan Glacier. Each consists of a one-inch wooden dowel 10 feet long set snugly in a hole bored 8 to 9 feet into the ice. Dowels are reset periodically as ablation demands, and all are reset at the end of summer so that most survive the winter in upright position. These stations are arranged in a longitudinal centre-line profile extending from the terminus to above the firn limit and in 8 complete or partial transverse profiles spaced at intervals along the ice tongue (Fig. 4).
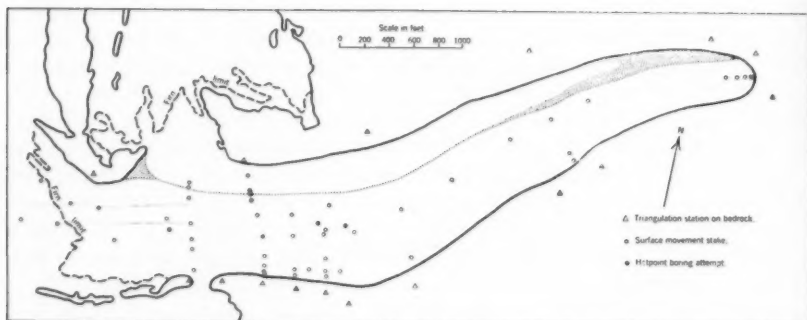
Fig. 4. Map of triangulation stations, surface movement stakes, and hotpoint boring sites.

Readings are made to a fixed mark on each pole by triangulation from a number of established stations on bedrock or stable deposits on the valley walls. Observations in 1952 were by transit and gave locations accurate to ±0.2 feet horizontally and to ±0.6 feet vertically for the most distant station, 4,000 feet. Most readings were over a much shorter distance, and the accuracy was considerably greater. A Wild T-2 theodolite used in 1953 gave vertical angles with accuracies several orders higher. Stations were generally observed every two weeks during the summers of 1952 and 1953.

Results to date. Reduction of these triangulation data requires laborious calculations not yet made, but inspection of the readings indicates that movements within the glacier are indeed oblique to the surface. The downvalley component for a few selected stations has been computed from the 1952 data. The maximum velocity recorded was in the mid-glacier position a mile below the firn limit, but it amounted to an average of only 1.2 feet per day over a

six-week period. Velocities along the mid-glacier stream-line decreased in a downvalley direction and most markedly in reaches of gentlest surface slope. This produces a shortening of the longitudinal distance between points on the glacier surface, which for the stakes measured amounted to 0.7 foot per day in a distance of 7,600 feet. If velocity is assumed constant over the year, this amounts to 260 feet annually, or a shortening of 3.4 per cent. This shortening could result from surfaceward movement at increasingly steeper angles downvalley, and it is compatible with the concept of compressive flow (Nye, 1952, p. 89). Movement with an increasing vertical component downvalley enables the glacier to maintain its surface profile and elevation in face of increasing ablation.

It was also found that the highest surface velocity gradient along a transverse profile, that is the greatest change in velocity per unit transverse distance, occurs within a 300-foot zone at the glacier's margin. On a transverse profile in the Castleguard sector the velocity 50 feet in from the lateral moraine was only 18 per cent of the maximum, but 100 feet farther in it was nearly 50 per cent. Furthermore, little difference in velocity, averaged through a 6-week period, could be detected across a zone 1,000 feet wide in the centre. A similar velocity distribution is common in valley glaciers, being more marked in some than in others (Hess, 1904, pp. 119, 124; Klebelsberg, 1948, p. 83; Nielsen, 1953, p. 10). An ice stream like the Saskatchewan with steep valley walls and a probable thickness of 1,000 feet close to the edges should have a steeper marginal velocity gradient than a similar ice stream flowing in a channel with gently sloping sides. Extreme marginal velocity gradients are found in glaciers experiencing *Block Schollen*, or "plug flow", in which practically the entire velocity change occurs in a marginal zone a few tens of metres wide, and the major part of the glacier moves as a unit like a solid body sliding down a chute (Finsterwalder, 1937, pp. 96–8; 1950, p. 385).

Short-interval velocity measurements. In 1952 density waves in the air spoiled an attempt to record the movement of this glacier by means of a time-lapse motion picture camera taking exposures at 45-second intervals. This procedure appears to have merit, but an environment different from that of the Saskatchewan, where the air waves caused apparent displacements of the target exceeding the actual amount of movement, is required for its successful application.

Daily measurement of velocity stakes opposite the Castleguard camp in 1952 revealed marked variations in flow rates at different points, so a similar but extended and more carefully controlled study was undertaken the next year. In 1953, 5 stakes arranged in a cross, one arm transverse and the other parallel to the direction of flow (Fig. 5), were observed at 12-hour intervals from August 17 to September 3. Bad weather and low visibility occasionally interrupted the observations. Distances to the stakes were known from triangulation so that measurement of horizontal angles permitted calculation of the downvalley component of movement. The observing instrument, a Wild T-2 theodolite, was enclosed in a tent to guard against wind and incident
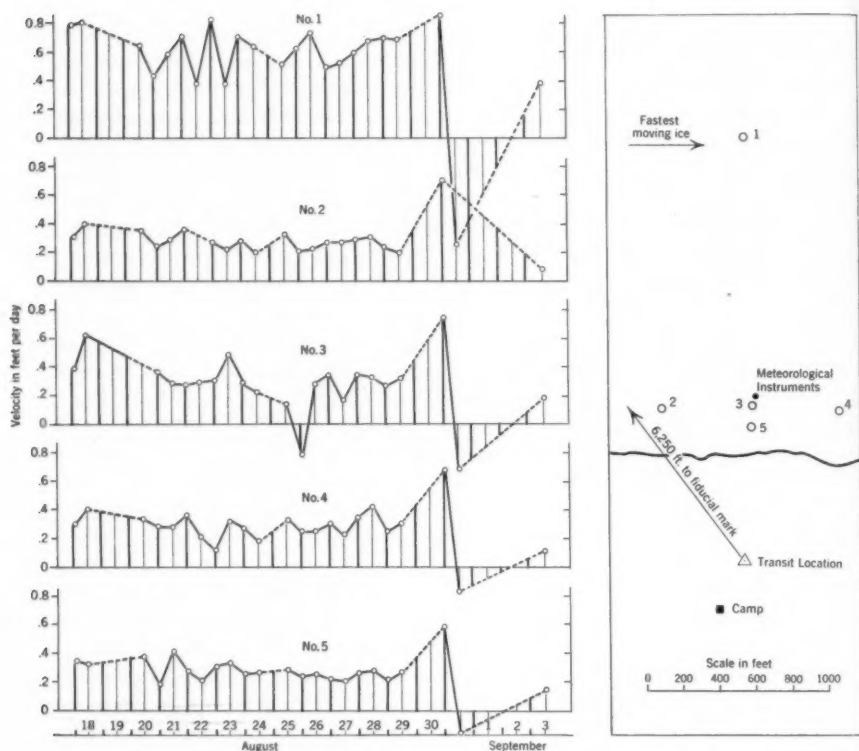
Fig. 5. Map and plot of short-period movement stakes. Readings plotted at mid-point of 12-hour observation intervals, specifically at 1 a.m. and 1 p.m.

radiation, and great care was taken to eliminate effects of diurnal drift in the instrument by turning all angles from a fixed mark on a bedrock cliff across the glacier. The observation point was on a flat area along the crest of an abandoned lateral moraine. Possibilities of creep or slump at this site cannot arbitrarily be dismissed, but the records show that it did not occur in perceptible amount during the study. All the movement stakes lie on the same side of the line from the station to the fiducial mark on the opposite side of the glacier, and a shift in the observing instrument would produce an apparent movement of the velocity stakes all in the same direction and of an amount inversely proportional to their distance from the instrument. No such behaviour was recorded.

The precision of measurement was tested by turning a fixed angle between two bedrock stations across the glacier, a little more than 6,000 feet from the instrument point, 50 times under various different conditions with different operators. The frequency distribution of these angles shows a standard deviation of 3.0 seconds of arc, which means that 95 per cent of the time the

measured angle was within 6.0 seconds of the true angle.   Six seconds of arc are equivalent to distances of 0.02 and 0.07 feet respectively at the nearest and most distant stakes.   An optical plummet on the theodolite reduced set-up errors to less than 0.01 foot, so, including possible inaccuracies arising from wind, it seems safe to conclude that the accuracy of measurement of velocity stake locations is, with rare exceptions, within 0.05 foot.

For purposes of graphic presentation, the velocities recorded for each 12-hour interval are plotted at the mid-point of the observation period, namely 1 a.m. and 1 p.m., and these points are connected by a straight line (Fig. 5). This is somewhat unrealistic as the movement may have occurred any time within the 12-hour interval, but since velocity changes are the matter of principal concern this representation is permissible.   Inspection of Fig. 5 reveals some erratic behaviours.   Some periods of acceleration affect all stakes simultaneously, but it also appears that rapid movement of one stake is not necessarily matched by proportionately rapid movement of its neighbours in either the longitudinal or transverse position.   For example, during the first half of August 18, stake No. 5 decelerated slightly while the others accelerated, especially No. 3.   During the second half of August 21 all points accelerated except Nos. 3 and 5 which decelerated, the latter markedly.   During the last half of August 25, No. 1 accelerated while all other stakes decelerated, but by the second half of August 26 when No. 1 started to decelerate the other stakes were accelerating, except No. 5 which decelerated slightly.   Ignoring for the moment the exceptional behaviour of August 31, individual stakes show velocity changes as large as 0.4 foot in successive 12-hour intervals, and the velocity difference between stakes during a single 12-hour interval is as great as 0.7 foot.   The largest fluctuations are displayed by stake No. 1 which is farthest out on the glacier where velocities are greatest.   It is clear that studies of this type should be made with respect to a number of stakes and not to just one, as is the usual practice.

In the last half of August 25, stake No. 3 actually receded 0.2 foot up-valley.   Isolated reverse movements of this type are probably due to backward slip or rotation of individual blocks within the crust of the glacier.   Many of the erratic accelerations and decelerations displayed by the various stakes may be due to shiftings of individual crustal blocks superimposed on a reasonably steady downvalley flow of the whole glacier.   This possibility could be tested by comparing the total movement of the various stakes over a longer period of time.   It seems unlikely that the erratic behaviours are due to refraction of sight-lines by differences in air density because such effects should apply in a similar sense to all the stakes.

The most striking behaviour recorded was a gradual acceleration followed by a sudden and larger deceleration, involving actual backward movement, shown by all stakes, except possibly No. 2 for which the record is incomplete, over the period August 29 to September 1.   This fluctuation occurred during a prolonged period of heavy precipitation, suggesting a meteorological cause. For reasons already given this exceptional behaviour cannot be explained by a shift of the observation point.   Washburn and Goldthwait (1937, p. 1,662)

recorded periods of deceleration on Crillon Glacier, Alaska, following rain storms but offered no explanation for this behaviour.   It may be that additional weight placed on the glacier by the precipitation sets up a longitudinal wave that passes through the ice in a downvalley direction, or perhaps a sudden local movement within the glacier, lubricated by the water, generates a similar wave.   Passage of a longitudinal wave through the ice could conceivably produce the type of behaviour recorded.   Critical evaluation of these highly speculative ideas is not possible with the scant data in hand.

Regular diurnal fluctuations in glacier velocity have been attributed to meteorological influences, particularly temperature and radiation (Krasser, 1939, p. 302; Klebelsberg, 1941, p. 375; 1948, p. 86; Drygalski and Machatschek, 1942, p. 112), although no wholly satisfactory explanation of the mechanics involved has been offered.   During the Saskatchewan study temperature and pressure data were collected by continuously-recording instruments on the glacier's surface, and these data were supplemented by general observations of cloud cover, wind, and precipitation.   A statistical analysis of the meteorological data has not been made, so the possiblity of correlation between daily velocity behaviour and the recorded meteorological variations cannot be evaluated.   A watch was kept for waves or impulses of increased velocity within the glacier that might be traced successively from station to station along the longitudinal profile, but none was recognized.

Englacial velocities

Knowledge of the magnitude and distribution of velocity within glaciers is essential to analysis of stress–strain relations under the pressures and temperatures attained at depth, to an understanding of the mechanics and mode of glacier flow, and to an evaluation of the role of basal slip in the movement of ice bodies with sloping floors.   Saskatchewan Glacier is an excellent subject for investigation of velocity–depth relations because of its relatively simple geometry and the data available on its various dimensions and behaviours.

For this purpose we planned to sink a pipe vertically through the glacier to its floor and to determine subsequent deformation of the pipe by means of inclinometer surveys, a procedure already used in other glaciers (Perutz, 1949; Gerrard, Perutz and Roch, 1952; Sharp, 1953).   Aluminum pipe, inner diameter 1.38 and outer diameter 1.65 inches, was selected for the drill stem because this permitted use of a small-diameter inclinometer in which bearings of inclination readings were given by magnetic compass.   Boring in the ice was by electrical hotpoints of 1.75 inches outer diameter, power being furnished by a portable 2,500-watt, 220-volt, AC generator driven by a small gasoline engine (Fig. 6). The hotpoints operated at a current of 8.0 to 9.5 amperes, and maximum boring speeds of 14 to 16 feet per hour were attained under normal conditions.

In 1952 borings were attempted at two sites near the centre of the glacier opposite the Castleguard camp (Fig. 4).   Both attempts were unsuccessful owing to burned out or shorted hotpoints and to seizures of the drill stem by shearing in the crustal ice.   The greatest depth attained was 150 feet.   A

Fig. 6. Hotpoint boring operation in 1952, August 3.

resurvey was made in 1953 of the pipe left in this hole, but deformation was too small to be significant.

In 1953 a better site was found higher up the glacier near the abandoned Army camp (Fig. 4). This proved suitable except for minor seizures of the drill stem, possibly caused by freezing within a vestigial chilled zone near the surface. The operation got off to a reasonably good start but ended in failure when the deepest hole, 395 feet, was lost in the process of replacing a shorted hotpoint. Failure of the 5 available hotpoints was the principal stumbling block in 1953. Further attempts will be made to bore through the glacier at this site.

Structures in the glacier

Most structures in glacier ice have been created by or because of flowage so that knowledge of their characteristics and origins can contribute to an understanding of glacier flow.

Sedimentary layering. The problem of distinguishing sedimentary layering from metamorphic foliation in glacier ice has long plagued glaciologists. Initially, this proved a troublesome matter on the Saskatchewan, but continued observation and experience brought conviction that both a relic sedimentary layering derived from the firn and a secondary foliation created by flowage could be recognized. Sedimentary layering is most easily identified close to

Fig. 7. Gently dipping sedimentary layering cut by essentially vertical flow foliation exposed in wall of crevasse nearly 3 miles below firn limit.

the firn limit where it consists of gently dipping layers of loose, granular, partly reconstituted firn alternating with ice layers and lenses of the type formed by freezing of meltwater percolating into firn (Sharp, 1951, pp. 609–14). These granular layers are much too thick and irregular to be the product of shearing. Farther down the glacier a foliation, which appears to be of secondary origin, becomes progressively stronger, and all doubt of its secondary nature is removed by exposures in which the foliation cuts across sedimentary layers at a high angle (Fig. 7). Isoclinally folded and contorted granular layers seen locally along the lateral margins of the glacier (Fig. 8) are probably sheared-out sedimentary beds, for the folded structures are transected by flow foliation.

In many places, outcrop traces of the granular layers are discoloured by an accumulation of fine silty dirt, although in fresh excavations the granular layers are no dirtier than the adjacent masses of solid ice. It seems likely, though not as yet certain, that the dirt on the granular layers is a surface deposit of wind-borne or water-washed material, secondarily acquired. Debris collects on the granular layers because of the irregular intergranular depressions, while it is washed off the smooth surface of adjacent areas of solid ice, as early recognized by Forbes (1859, p. 21).

Fig. 8. Contorted sedimentary(?) layering near south margin of Saskatchewan Glacier, 28 July 1952.

Outcrop pattern of sedimentary layering. The attitude and structure displayed by sedimentary layers within the Saskatchewan Glacier raise a most puzzling and enigmatic problem. Viewed from a high vantage point, the surface of this glacier displays a faint pattern resembling that of truncated beds in a plunging fold (Fig. 9). Similar patterns are reported on the surfaces of other glaciers (Streiff-Becker, 1952, p. 5). Alternate bands of dirty and relatively clean ice describe broad sharp-pointed curves transversely crossing the Saskatchewan Glacier from the medial moraine on the north nearly to the south margin. These bands are most prominent within the first two miles below the firn limit. They die out toward the margins and become progressively fainter downvalley although recognizable to within one mile of the terminus (Fig. 10). Disappearance of the bands is probably due to recrystallization of the ice with elimination of the granular layers on which dirt tends to accumulate. Spacing and width of the bands are not uniform, and the curves become sharper and of greater axial length downvalley. After considerable ablation in summer, the dirtier bands can be traced across the glacier's surface by an experienced observer on foot, and they are found to be conformable with the sedimentary layering earlier described.

Fig. 9. Looking up Saskatchewan Glacier from south wall, 24 August 1952. Note outcrop pattern of sedimentary layering on surface of glacier. Short dark streak in centre mid-distance is abandoned Army campsite.

As initially laid down in the accumulation area the sedimentary layers were probably inclined gently downglacier, but subsequent flowage according to the concepts of Reid (1896, p. 919) should eventually give them an upvalley dip. The assumed age of the layers and their outcrop patterns would thus lead one to expect an open synclinal structure with the axis nearly horizontal or plunging gently upglacier, but such is not the case. The structure of the sedimentary layers, at least as determined from direct dip and strike readings, is actually an anticline plunging 8 to 14 degrees downglacier (Fig. 10), which is steeper than the slope of the glacier's surface. This means that ice at the surface should be younger toward the terminus and older toward the firn limit. The seeming absurdity of this raises serious doubt as to the validity of the field observations, but repetitions of the observations have not yet produced anything different. This is an enigma for which a suitable explanation has not yet been found.

Flow foliation. Much of the ice exposed on the surface of Saskatchewan Glacier and in the walls of its crevasses displays a well-developed flow foliation consisting of alternating laminae, a fraction of an inch thick, of white bubbly ice and denser bluish ice. This structure is strongest along the margins of the glacier and is prominent near the medial moraine.

In the centre near the terminus, foliation planes are spoon-shaped and dip gently upglacier.   One mile above the terminus they are much steeper and trend parallel to the margins even in the centre where dips are essentially vertical. Along the margins dips are mostly 50 to 75 degrees inward.   The nature of the transition from transverse spoon-shaped folia to steep longitudinal folia is obscured by an intervening zone of contorted ice.   This difference in the shape and orientation of foliation planes has long been recognized (Forbes, 1859, p. 19), but a satisfactory explanation has never been offered.   The following comments are wholly speculative.

Flow foliation is most strongly developed where velocity gradient is highest (shear stress is greatest) and where the physical state of the ice is such that it yields primarily along closely spaced shear planes.   Throughout the length of the glacier the extreme basal foliation, if such exists, is probably essentially conformable to the valley floor except for divergences related to surfaceward movement of ice.   Where the glacier exceeds a certain thickness, foliation planes of similar shape and orientation are not formed clear to the surface of the glacier because the ice at depth yields readily and prevents the drag of the floor from having any noticeable effect on ice at the surface. The surface ice, yielding less readily, is presumably influenced by marginal drag to the extent that a weak foliation is formed essentially parallel to the lateral margins, as actually observed.

The exact mechanics involved in the formation of foliation remains something of a problem upon which the Saskatchewan data throw little light.   Thin sections cut across zones of granulated ice, apparently formed by shearing, show some evidence of recrystallization, and this has been proposed as a way in which foliation is formed (Philipp, 1920, pp. 502–3).   It has also been suggested that reorientation of crystals involving recrystallization, migration of crystal boundaries, and similar processes acting along specific planar layers during solid flowage create the dense folia (Perutz and Seligman, 1939, p. 354). However, crystal fabric diagrams from the Saskatchewan and some other glaciers, although seemingly related in orientation to the foliation, do not show, so far as our understanding extends, that reorientation and recrystallization have occurred more extensively in the dense folia than in the adjacent ice. Individual crystals actually extend through two or more folia, and it may be that recrystallization following development of the foliation has destroyed differences in crystal orientations that formerly existed between adjacent folia. It can only be said that foliation in the Saskatchewan Glacier appears to have been formed by flowage and to be conformable with the planes of greatest shear strain in the ice.   Some exposures show two sets of foliation planes of different orientation, age, and stage of development suggesting that new folia form as the stress orientation changes during flow.

Faults. Faults of small displacement offset the foliation in the terminal and marginal parts of the glacier.   Near the terminus are many transverse low-angle thrusts, most of which dip upglacier, suggesting that compressive flow prevails (Nye, 1952, p. 89).   A few dipping downglacier are probably
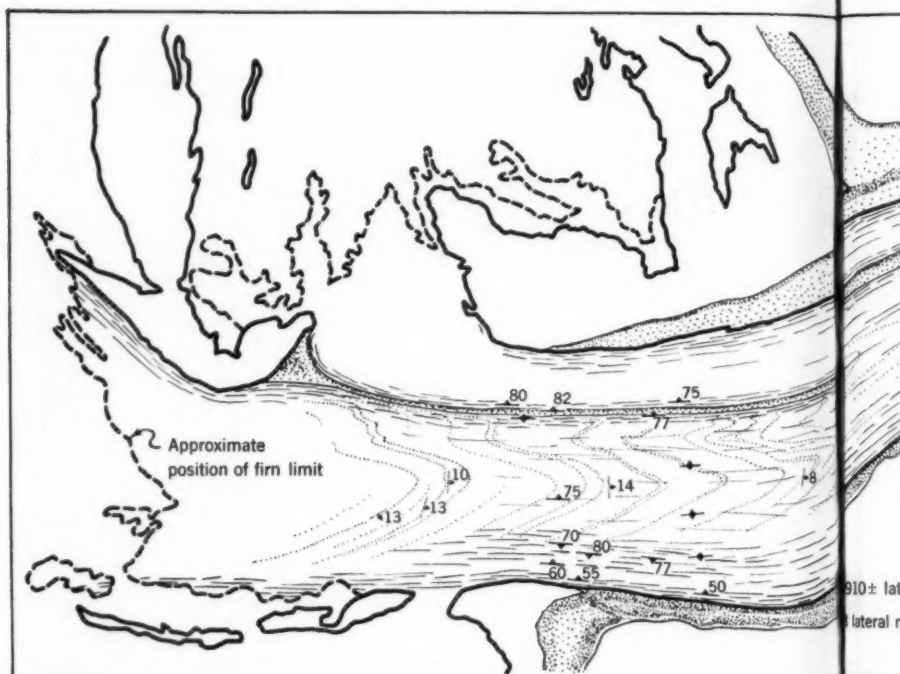
Fig. 10. Structural map of sedi㎖ing and

conjugate to the predominant set. The terminal zone also displays a number
of transverse high-angle reverse and normal faults. Although some of the
latter resemble structures produced by extending flow (Nye, 1952, p. 89), it
seems more likely that they are the product of buckling and settling of crustal
blocks.

Marginal faults, studied chiefly along the south edge of the glacier, are
mostly strike-slip in nature with apparent left-hand displacements of a foot or
less. Depression of the downglacier block in some instances indicates move-
ments that are oblique rather than strictly parallel to the strike. The location,
distribution, nature, and orientation of these marginal faults suggest that they
are the result of adjustments within the glacier related to slight bends or other
irregularities in the valley walls.

Crevasses. Saskatchewan Glacier displays crevasses of 5 different types,
all but the last of which can probably be explained by a stress analysis similar
to that used by Nye (1952, pp. 89–91). The most common crevasse has a
curved trace concave upglacier and passes from a longitudinal orientation near
the centre to a 45-degree transverse orientation near the margin (A, Fig. 11).
Such crevasses mostly die out within a few hundred feet of the margin, and

Overridden moraine
1930+ moraine
1893 moraine

Scale

| 0 | 200 | 400 | 600 | 800 | 1000 | Feet |

| 0 | ¼ | ½ | ¾ | 1 | Mile |

8 Sedimentary layering, showing strike and dip.

45 Flow foliation, showing strike and dip.

N

910± lateral moraine

lateral moraine

M.T.M.
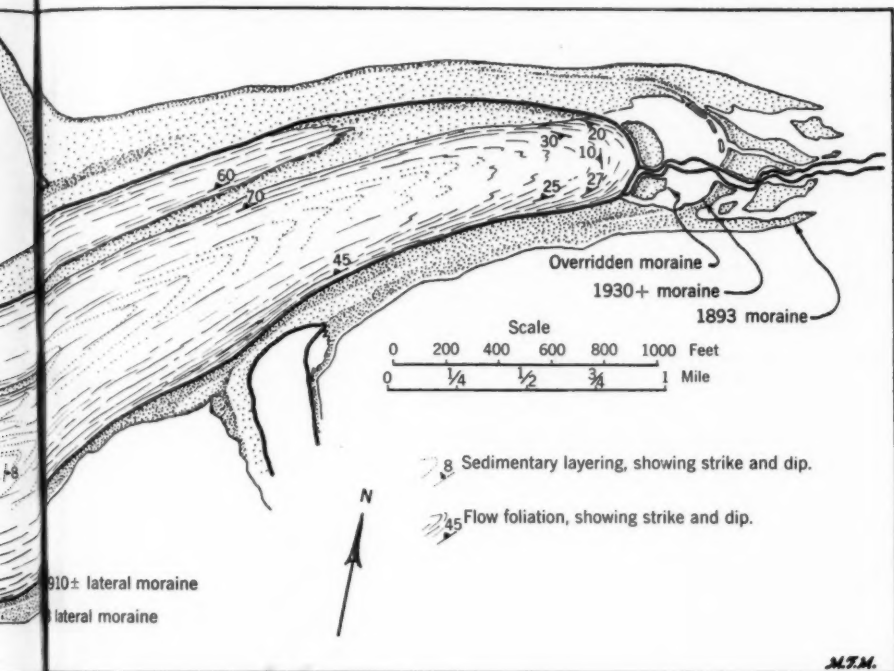
of sed ng and foliation at surface of glacier.

only a few extend to the glacier's edge which they intersect at 45 to 75 degrees. Crevasses of this type are abundant in the Castleguard sector where the glacier attains its greatest width. The central longitudinal trend may be related to lateral spreading of the ice in this wider part, and the gradual change to an oblique trend is probably due to the increasing influence of tensile stresses generated by a high velocity gradient near the margin. Relations between these stresses and transverse velocity gradients are being studied quantitatively.

Transverse crevasses convex upglacier constitute the second type recognized and are seen in the steep lower reach of the north-bank tributary (B, Fig. 11). The convex longitudinal profile of the glacier in this reach, related to a steepening of the rock floor, appears to be the cause of these crevasses. Their upglacier convexity is probably related to the marginal velocity gradient which gives rise to tensional stresses oblique to the glacier's margin.

The same tributary shows an interesting change in character, longitudinally, which is largely responsible for longitudinal crevasses in its lower part, the third type of crevasse distinguished (C, Fig. 11). The upper reach of the ice stream is confined in a steep-walled valley, but the lower half flows in an unconfined course down the steep wall of the trunk valley; in effect it becomes a "wall-sided glacier" (Ahlmann, 1940, p. 192). A cross section of the ice

stream in the upper reach would show a relatively flat upper surface and a curved bottom. A cross section in the lower reach would be just the opposite, a flat bottom and an upper surface convex to the sky. This transverse convexity plus the spreading of the ice in the unconfined lower reach accounts for the longitudinal crevasses.

The fourth type of crevasse is simply a straight marginal fracture trending obliquely upglacier (D, Fig. 11). Marginal crevasses have probably been integrated into the transverse crevasse systems already described, but they also exist as independent entities in Saskatchewan Glacier. They are the product of oblique downglacier tensile stresses set up within the marginal zone of steep velocity gradient, without perceptible complication by other stress systems.

The fifth and most unusual type of crevasse consists of narrow belts of short *en échelon* cracks, best seen along the south margin near the bend below the Castleguard sector (E, Fig. 11). These subequally spaced belts diverge only a few degrees from the direction of flow, although the individual cracks are about 45 degrees to the flow direction and essentially parallel to neighbouring transverse crevasses (Fig. 12). No satisfactory explanation has yet been evolved for these crevasse belts, but they may be related to shear couples set up by the obstructing effect of the valley wall at the curve. The only other parts of the glacier displaying such crevasses are the north and south margins just below the entry of the north-bank tributary. Here the glacier is crowded forcefully against the valley walls to make room for the additional ice, and this may give rise to the exceptional marginal shear stresses required to produce belts of *en échelon* crevasses.
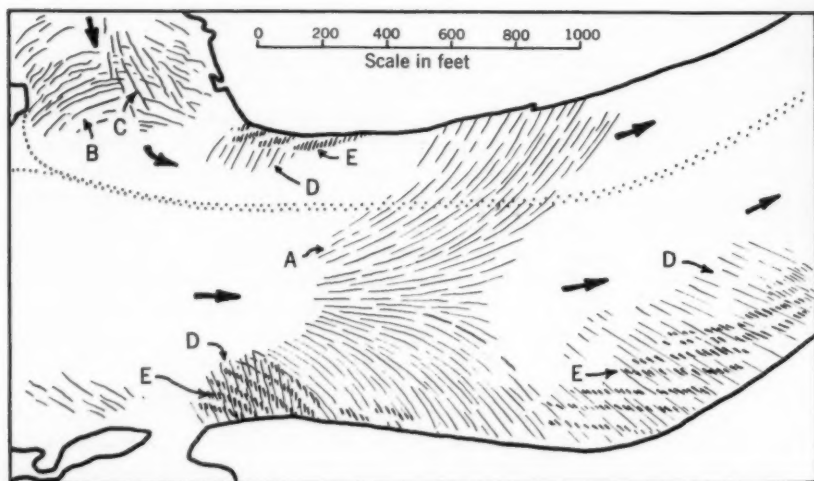
Fig. 11. Map of crevasse types in Castleguard sector. A—transverse crevasses concave upglacier; B—transverse crevasses convex upglacier; C—longitudinal crevasses; D—marginal crevasses; E—belts of *en échelon* crevasses.
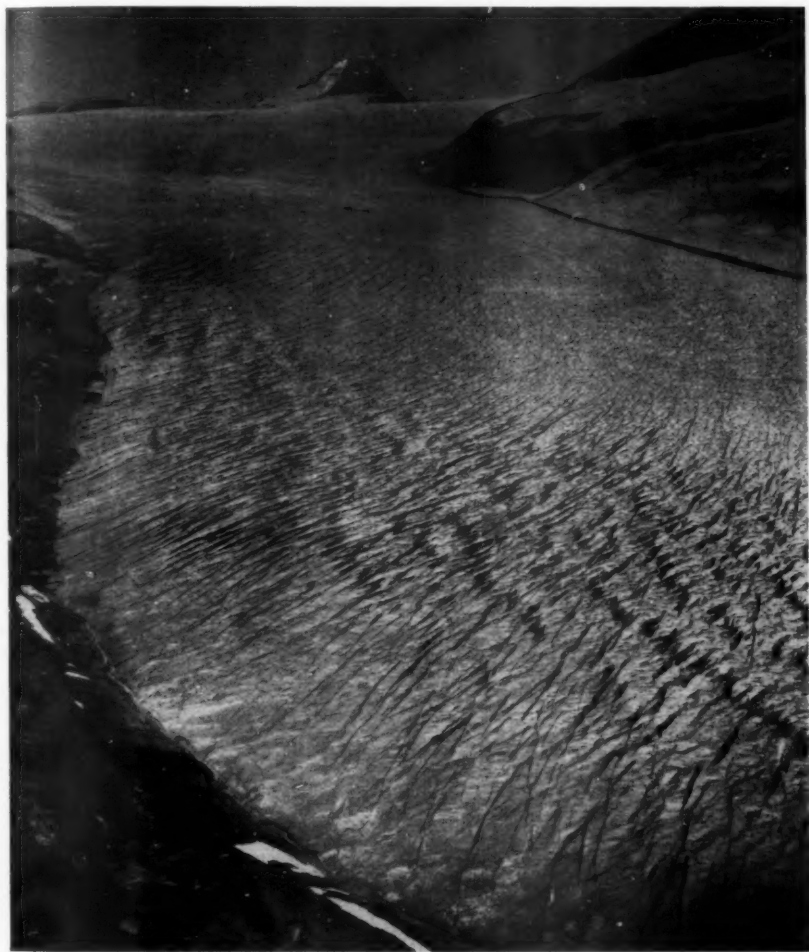
Fig. 12. South margin of glacier in Castleguard sector showing belts of *en échelon* cracks and large transverse crevasses concave upglacier. Transverse and longitudinal crevasses are also visible in tributary at right. Columbia Icefield and Mt. Columbia on skyline, 13 August 1953.

Crystal fabrics

Method and procedure. The optical orientation of ice crystals was determined in the field by means of a large universal stage mounted between crossed polaroid sheets. Fabric diagrams were constructed in the conventional manner by plotting optic axes on the lower hemisphere of a Schmidt equal-area net. All sections were cut in a vertical plane parallel to the
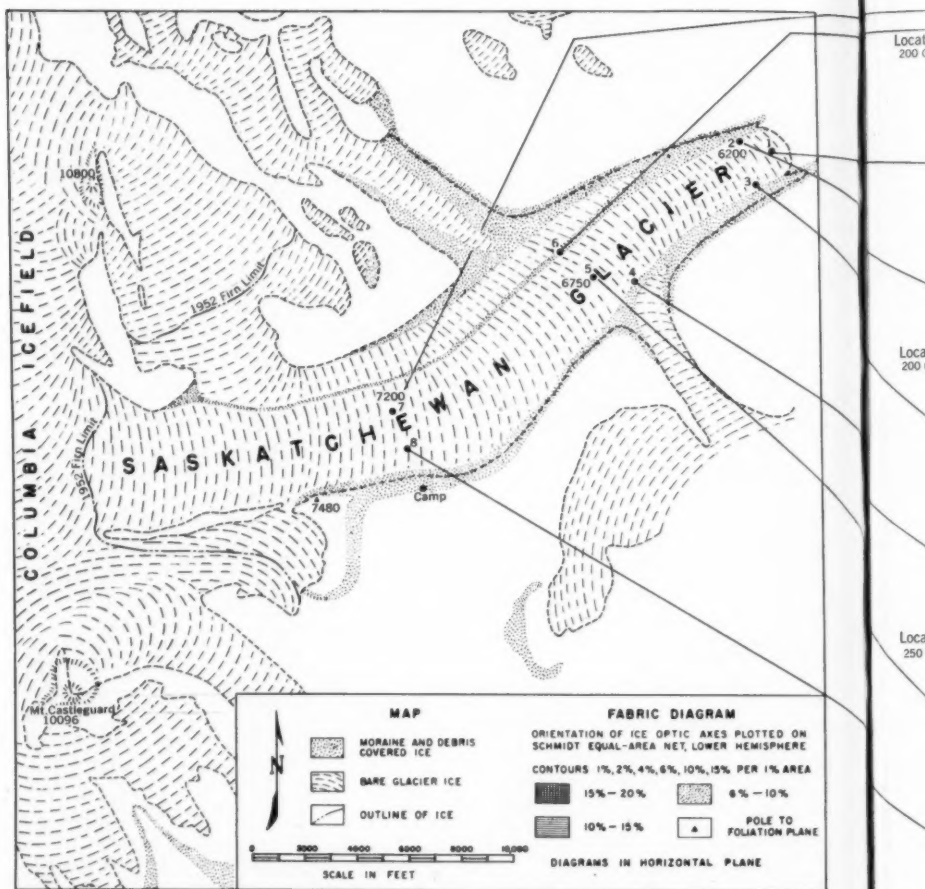
Fig. 13. Map and crystal [ ]ms for

foliation, but the diagrams were subsequently rotated to a horizontal position to facilitate comparison with other data.

Either 200 or 250 grains were measured at each of 8 locations on Saskatchewan Glacier as shown in Fig. 13. The Saskatchewan diagrams have weaker and more varied patterns than found on either the Emmons Glacier, Mt. Rainier (Rigsby, 1951, p. 594), or the Malaspina Glacier, Alaska (Bader, 1951, pp. 531–2; Rigsby, 1953, p. 17).

Diagrams from locations 1 and 2 near the Saskatchewan terminus have several strong maxima clustered about the pole to the foliation plane and closely resemble the predominant pattern found on the other glaciers. Curiously, the diagram at location 3, also in the terminal area, is weaker and distinctly different, resembling closely those at locations 4 and 5, a mile farther
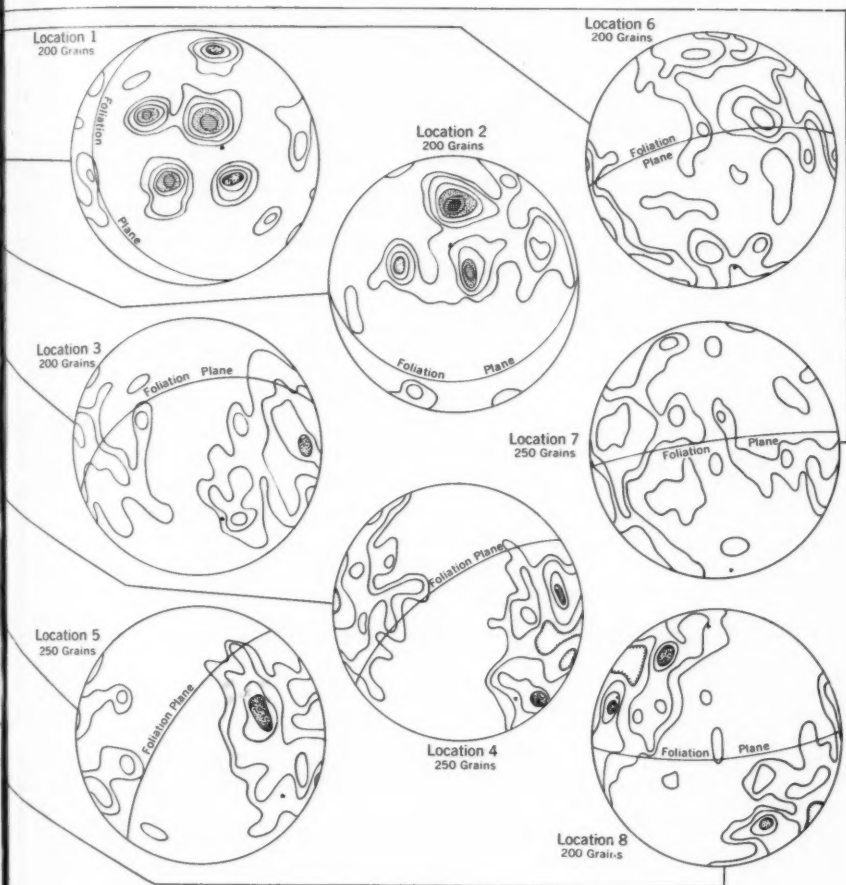
rystal **ms** for Saskatchewan Glacier.

up the glacier. The diagram at location 6, geographically associated with locations 4 and 5, is still different and is more like that at location 7, 2.5 miles farther upglacier. The diagram at location 8 is more like those at 4 and 5 than that at nearby location 7. It appears that the stronger patterns exist in the more extensively metamorphosed and presumably older ice. Most fabric patterns from Saskatchewan Glacier are weaker than those from the Emmons and Malaspina glaciers because the Saskatchewan ice has been less extensively reconstituted as shown by the preservation of sedimentary structures far below the firn limit.

The patterns at locations 6 and 7 appear too weak to have much significance. The patterns at 3, 4, 5, and 8 all show an offset of the maxima to the same side of the pole to the foliation plane. At locations 3 and 4 this may

have something to do with proximity to the glacier's margin, but the actual cause and significance of the relation are not known. A satisfactory explanation for strong patterns like those at locations 1 and 2 in which a number of maxima cluster about the pole to the foliation plane is still being sought. The tentative suggestion that ice crystals may yield along planes other than the basal glide plane (Rigsby, 1951, p. 597) is not supported by any independent data known. A recent suggestion by Schwarzacher and Untersteiner (1953, pp. 122–4), relating such patterns to slip on the basal glide plane of crystals properly oriented along several sets of shear planes within the ice lying at an angle to the foliation, is a possibility that merits further investigation.

The direct relation between strength of crystal orientation and degree of metamorphism and the clustering of maxima around the pole to the foliation plane certainly suggest that the crystal fabrics are related to flowage. However, it may be that the fabrics observed in ice on the glacier's surface are a secondary product formed by a recrystallization that proceeds according to certain laws or controls from a previously well-oriented arrangement established by flowage. Evidence for recrystallization following development of foliation has already been cited. Clearly, the interpretation of fabric diagrams from glacier ice needs the aid of laboratory experimentation, and such work is now being undertaken by Rigsby.

Miscellaneous investigations

Ablation. A determination of total regime was not attempted on this glacier, but gross measurements of surface ablation were made at movement stakes on the ice tongue below the firn limit. These data will be useful as a means of assessing the relative effects of ablation and surfaceward flow upon the glacier's profile. Ablation during summer on the Saskatchewan differs markedly in time and space. It ranged from 0.8 to 4.7 inches of water per day in 1952.

Ablation is greatest near the terminus, an estimated 25 to 30 feet of ice per season, but the progression of average daily ablation from lower to higher points is not an orderly decrease. Ablation during part of the summer of 1952 along the centre-line of the glacier in the Castleguard sector averaged 1.65, 1.99, 1.48, 1.65, and 1.91 inches of water per day from the lowest to the highest station. These figures reflect subtle variations of the local environments as well as differences in the nature of the materials being melted. Still greater differences are found in areas lightly covered by debris, and in proximity to the valley walls where excessive melting produces a marginal depression.

Glacier fluctuations within the last century. The following features are found within the first mile beyond the present terminus of Saskatchewan Glacier: (1) an old, broad, overridden moraine barely 1,000 feet beyond the terminus, (2) a trim-line in mature timber on the north valley wall clearly related to (3) a bouldery moraine 4,000 feet down the valley, (4) a more recent small double moraine 1,800 feet from the terminus, and (5) four distinct terrace levels in the proglacial outwash, each of which is related to a recognized

phase of the glacial history. Except for the overridden moraine, the end moraines can be traced upvalley into lateral moraines displaying the same relative position and characteristics.

By means of tree-ring relations along the trim-line, C. J. Heusser (personal communication) demonstrates that part of the trim-line and the outermost moraine are the products of an advance culminating in 1807. The age of the trees outside the trim-line shows that this was the greatest advance in at least a century. A higher part of the trim-line farther up the valley was formed by a later advance culminating in 1893 as previously reported (Field, 1949, p. 109). The overridden moraine described herein may have been formed during recession from the 1807 position and subsequently overridden by the 1893 advance, or it may be still older. Observations of the glacier since 1893 have been frequent enough to show that this moraine was not formed subsequent to 1893. Old photographs indicate that the small double moraine 1,800 feet from the present terminus was formed between 1930 and 1935.

Oxygen isotope studies. Recent investigations of the ratio between oxygen 18 and oxygen 16 in waters of various origins have revealed interesting and significant differences (Epstein and Mayeda, 1953). Snow and the meltwater from glaciers are exceptionally low in O^{18}. With the thought that differences in the O^{18}/O^{16} ratios within glaciers might be related to the original environment of precipitation or to the subsequent history of the ice, 38 samples of ice were collected on the surface of Saskatchewan Glacier along a traverse from the firn limit to the terminus. Analysis of these samples by mass spectrometry is currently underway, and only preliminary results are available. Significant differences in the O^{18}/O^{16} ratios exist within this glacier, but no consistent trends or relations have yet been worked out.

Five samples of ice were also collected along a profile from the firn limit to the terminus at the request of W. M. Campbell of Atomic Energy of Canada. This organization analysed the specimens for deuterium by mass spectrometer with results suggesting no enrichment of deuterium in the ice over that present in other natural waters.

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A NOTE ON
CLIMATIC CHANGE IN THE SEA

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THE recent warming in the world's climate has been particularly striking in the North Atlantic region. An increase in solar heating would be expected to make itself apparent in increased circulation between the tropics and the poles in both atmosphere and hydrosphere, and there is ample evidence that it has occurred in both (1, 2, 3, 4). In the North Atlantic, it is in the Gulf Stream–North Atlantic Drift system that the change has been most violently manifested, involving an increase both in temperature and in water transport. The effect has been strongest in the northeastern part of the system (Iceland, Faeroes, Barents Sea, Svalbard) and in west Greenland, where the Irminger Current has been responsible for the change in marine climate.

In this process, as in most changes in nature, there has been an obvious element of self-regulation, or of a mechanism whereby the effects of the change are damped by processes set up by the change itself. An increased flow of Atlantic water northward to the Arctic Ocean requires an increased flow of polar water southward, so that the two areas most influenced by the polar outlets—east Greenland and the Canadian Eastern Arctic—would be expected to be buffered against the climatic change; and it is in fact in those two regions that the climate has changed least in the whole of the North Atlantic area in the past thirty-five years. Thus any warming effect in those two regions does not necessarily bear a simple or direct relation to the increased volume or velocity of the whole North Atlantic circulation.

This appears to have been demonstrated in the relative strengths of the increases in North Atlantic circulation in this most recent warming (1915 to the present, or more properly to about 1945) and in the short warm period before that, which occurred in the 1880's and perhaps in the late 1870's. The effect of the 1915–45 period has been most strong in Svalbard and in west Greenland, and comparatively unimportant in east Greenland and the Canadian Eastern Arctic. In the 1880's there is evidence that the effect was stronger in the "buffered" areas, at least as far as the Canadian Eastern Arctic is concerned.

The evidence for a short period of climatic "amelioration" in the decade of 1880 in west Greenland and in Svalbard is well known (2, 3, 5). Compared with the present effects there that warming was a mild affair. Although the Atlantic cod (*Gadus callarias*), which serves as a good indicator of warming marine conditions in the northern part of its range, did in fact appear in both Svalbard and west Greenland at that time, the invasions were insignificant

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compared with the present enormous populations there. But in the Canadian Eastern Arctic, as represented by Ungava Bay and possibly also Frobisher Bay, the story appears to have been different.

The existence during the 1880's of warmer conditions in Ungava Bay than prevail there today is indicated by the observations of Mr. Lucien Turner, who spent the period of 1882–4 at Fort Chimo on a commission from the U.S. Corps of Signals as one unit in the International Polar Year Expedition of 1882. Although there do not appear to be records of sea temperatures observed, Turner's manuscript report on the fishes collected (never published) records that the Atlantic cod was moving northward at that time "even to far north of Cape Chidley", and that the caplin (*Mallotus villosus*) was also moving northward year by year, and into Ungava Bay. On the subject of the caplin he writes: "Within Hudson Strait they had not been detected until several years ago when a few were seen in the neighboring waters of George's River. In the spring of 1884 they were observed in great numbers in that vicinity. On the 8th of August 1884 a school of several thousand individuals appeared four miles within the mouth of the Koksoak River. As many as were desired for specimens were secured by the hand as they swam near the shore . . . . This is the first instance known either to whites or natives of the appearance of the Capelin in the southern portion of Ungava Bay."[1]

During four seasons of intensive collecting in Ungava Bay from 1947 to 1950, the *Calanus* expeditions, using dredges, trawls, and hand-lines, took only two young specimens of the caplin, and none was found in the stomachs of seals or of Atlantic cod at Port Burwell (6). Moreover the temperatures measured in Ungava Bay were somewhat low for the normal caplin range, being never above 5.8°C at the surface nor above 2.5°C at 10 metres.

The presence of Atlantic cod in Ogac Lake, a saltwater lake on the shore of Frobisher Bay (7), may also be relevant to this matter. The locality lies over one hundred miles from the northernmost present occurrence of the cod (Resolution Island), and the cod is not found in the waters of Frobisher Bay itself. The Ogac Lake cod must therefore have reached the lake during a former period of warmer climate. The 1880 period is the most likely, for the lake is very small and the survival of an isolated cod population in so confined a habitat for longer periods of time is not probable.

Other relics of warmer climate at present alive in the Canadian Eastern Arctic may perhaps be less valuable as indicators in this particular context, but they should be mentioned here. The eel-grass (*Zostera marina*) has been recorded in southern Hudson Bay and in James Bay (8). It appears to have been known in Hudson Bay, however, as early as the time of Rae (9), and moreover there is the possibility that it dispersed there from the Gulf of St. Lawrence by way of a post-glacial marine connection (10), or by the agency of birds. The copepod *Acartia clausi* is known from James Bay and southern Hudson Bay, but is elsewhere known from Atlantic areas (southern Labrador, Gulf of St. Lawrence, southern Iceland, Norwegian coast, and southwards

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[1] I am indebted to the Smithsonian Institution for the loan of Mr. Lucien Turner's manuscript on the fishes of Ungava Bay, and of his caplin specimens.

to west Africa (11)). It is not recorded from west Greenland. The caplin, again, is common in Hudson Bay but rare, as has been mentioned, in the region of Hudson Strait. As in the case of the Atlantic cod in Ogac Lake, Frobisher Bay, and setting *Zostera* aside as a more doubtful example, it is questionable whether these marine animals could reasonably be supposed to have survived several thousand years since the last major climatic maximum in Hudson Bay; it is more likely that they are relics of a much more recent warming.

The inference is that the warming of the marine climate in Ungava Bay and probably in the Eastern Arctic generally in the decade of 1880 was of greater power than any that may be occurring there now; yet the present warming in west Greenland is undoubtedly of far greater extent than that of the 1880's.

The reason for this is possibly to be found in the relative volume transports and velocities of the Atlantic Drift system in the two periods. A large increase in flow, such as has been stimulated in the present or recent warm period, would have two important secondary effects: a) the flow out of the Arctic Ocean would be increased, as mentioned above (and it is to be noted that the thickness of the polar water layer in the Arctic Ocean has decreased considerably during recent decades (12)); and (b) the Canadian Arctic Current and the West Greenland Current, the latter with a large proportion of Atlantic (Irminger) water, would be pressed with greater force against the coasts of Baffin Island and west Greenland respectively, since the Coriolis force is proportional to the mass and the velocity of the moving body. This would have the effects of forcing more arctic water from the Canadian Arctic Current into Hudson Strait and Ungava Bay, and of minimizing the westward flow of West Greenland water over to the eastern end of Hudson Strait. It has in fact been established (2) that the extent to which the West Greenland Current holds close to the Greenland coast is proportional to the transport of the current, which varies from year to year.

If it is assumed that the warming of the 1880's involved a much lesser increase in current transport than did the 1915–45 period, which is a reasonable assumption, it follows that the effect in the Canadian Eastern Arctic may have been greater then than now, owing to the much lesser buffering effect of the Canadian Arctic Current and the lesser value of the Coriolis force acting upon the West Greenland Current. And since there is good evidence that the recent warm period has reached its maximum, at least temporarily (4, 5), we may expect, as the transport in the current system relaxes, that the cooling effect will be most noticeable in west Greenland and in the northeast Atlantic area, and that the Canadian Eastern Arctic region, probably at least as far south as the Gulf of St. Lawrence or Nova Scotia, may go through a further period of warming before the general cooling takes effect.

If the present apparent relaxation of the Atlantic circulation gives place in due course to an increased circulation again, which is probable, giving a northward transport of heat to a degree greater than during the recent warm period, then we should perhaps look forward to a time when the cold upper

layer of polar water in the Arctic Ocean is finally "flushed out". If and when that happens, the climate of the north will no doubt become suddenly considerably milder, and moister.

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THE ICE AGE AND MAMMAL SPECIATION
IN NORTH AMERICA

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A NUMBER of effects of the Ice Age on life in northern North America have been briefly reviewed by Flint (1952) in an earlier number of this journal. To these should be added another, the effect of glaciation on speciation of plants and animals. This aspect of the Ice Age in North America has received some attention in regard to plants and birds and here it is shown to have had an effect on some mammals.

As I pointed out in discussing the effects of glaciation on birds (Rand, 1948) in continental areas, when a wide ranging species varies geographically and is divided into a number of subspecies, the usual pattern is for a gradual change from one subspecies to another, the width of the area of intergradation being wider or narrower depending on the suddenness of the change of ecological conditions. As long as these subspecies are in contact they inter-breed, there is gene flow between the populations, and they all remain one species. Geographical isolation by physical barriers seems necessary for a population to evolve further, to the species level. In this isolation the two parts of the population gradually change by random mutation toward a state in which interbreeding with other populations is impossible. Then, when the barriers disappear, or are surmounted, the two descendents of the one ancestral form meet. What happens now depends on how far the process of speciation has gone. If it has not gone to the point where biological discontinuity is complete, they meet each other as subspecies and interbreed. If biological discontinuity has been achieved and their ways of life have become different enough they invade each other's territory and live together in the same areas as sympatric species.

In birds in northern North America there are a number of cases where forms meet that fit neither extreme. They have reached a point where they do not intergrade as ordinary subspecies, but their ways of life are still so similar that they are unable to invade each other's territory, and in some cases hybridization occurs, but only in a narrow zone. Examples are the gull complex of the *Larus argentatus–thayeri–kumlieni–leucoptera* complex; the large and small Canada geese of the *Branta canadensis* complex in the Arctic, and the spruce and Franklin's grouse (*Canachites canadensis* and *C. franklini*) that meet in the Rocky Mountains of British Columbia and Alberta. These phenomena correlate well with postulated effects of isolation by glaciers during the Ice Age: populations which had been isolated in refugia on the fringe of the ice met again with the retreat of the glacier, and the present zones of contact are therefore secondary. The refugia which seem to be

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indicated are: one (or more) southeast of the ice; two (or more) southwest of the ice in the Rocky Mountain area; one (or more) in the Alaska–Bering Sea area; and one in the arctic islands (this need not have been permanent in location, but have been slowly moving and transient in any one locality).

The correlation of bird data and postulated Ice Age effects makes it advisable to examine some mammal examples (basing classification on Anderson, 1946),[1] illustrating this idea:

(a) A Bering Sea area and a southeast refugium

The tundra shrew (*Sorex tundrensis*) of Alaska, northern Yukon, and northern Mackenzie is replaced to the south and east by the closely related saddle-backed shrew (*S. arcticus*), that ranges from northeastern British Columbia and central Mackenzie east and south to eastern Canada. This seems to indicate a Bering Sea refugium and one south and east of the ice. Later there was a subsequent spread, in which the southeastern member was the most active, and a secondary meeting in the same habitat. Though now without geographical barriers to separate them, the way of life of these two animals is apparently so similar that they have been unable to penetrate each other's habitat.

(b) A southeast and a southwest refugium

The red squirrels provide an example that correlates with two refugia south of the ice. *Tamiasciurus hudsonicus* is widespread in the coniferous forests, from the Atlantic north to the limit of trees, and west to Alaska and western British Columbia including Vancouver Island. However, in southwest British Columbia along the coast the douglas squirrel (*T. douglasii*) takes its place, and when the two meet they do not intergrade. The ranges of two species of marten are somewhat similar: *Martes americana* is found in the coniferous forest from northeastern North America to Alaska and British Columbia but is replaced west of the coast mountains by *Martes caurina*. In these instances, too, the eastern form has been the more active in spreading over much the larger area.

(c) A Bering Sea area and a southwest refugium

The thinhorn sheep (*Ovis dalli*) in its various local colour phases ranges from Alaska and Yukon into extreme northern British Columbia, to be replaced to the south by the bighorn sheep (*Ovis canadensis*). The ranges nearly, if they do not quite, meet and there is no sign of intergradation between the two species.

A similar pattern is evident in the ranges of the two closely related ground squirrels. The Columbian ground squirrel (*Citellus columbianus*), that ranges in the mountains of central British Columbia and central western Alberta southward, is replaced in northern British Columbia and northward by the closely allied arctic ground squirrel (*Citellus parryii* including *plesius* as a

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[1] I follow this standard list of names though later taxonomic work, notably that of Rausch (1953), has suggested some changes for nomenclatural reasons or because of changes in species limits.

subspecies). The arctic ground squirrel, however, shows a change in distribution pattern that adumbrates the distribution of some of the following examples. Adapted to alpine and tundra conditions of the north it was not restricted to the mountains as was its southern relative, and spread across the tundra of the northern mainland to Hudson Bay.

The relationships of the grizzly bears (genus *Ursus*) have to be worked out, along the lines indicated by Rausch (1953, pp. 96–7), but from my cursory observations there are three main types in the north: a small Barren-Ground type of interior Alaska, Yukon, and the mainland Barrens of the Northwest Territories; a huge coastal Alaskan type (including the big brown bears); and the large bears of the Rocky Mountains and plains. If this be the case, it would fit the picture of two refugia in the Alaska area; and one refugium (or more) southwest of the ice. The picture farther south may be more complex. Apparently there was a large grizzly on the plains of Canada at least, but it was the small Yukon type, adapted to northern conditions, that spread east onto the Barrens.

(d) A Bering Sea area and a southwest and southeast refugium

A similar picture, but involving three refugia, is shown by the genus *Microtus*. The three species: meadow mouse (*M. pennsylvanicus*), tundra mouse (*M. operarius*), and Townsend mouse (*M. townsendii*) are largely representative species that do not intergrade where they meet or overlap. The meadow mouse ranges from the northeastern United States and eastern Canada to the Cascades of British Columbia, to be replaced in the extreme west by the Townsend mouse. To the north the meadow mouse meets the tundra mouse in central Yukon, where the latter replaces it at higher altitudes. In the Arctic farther east, the meadow mouse extends to the wooded mouth of the Mackenzie, and in Keewatin extends onto the southern Barrens, but on the Barrens fringing the Arctic Ocean at Coronation Gulf it is the tundra mouse that has won the race to occupy this area, while neither as yet seems to have occupied the Barrens of northern Keewatin.

The red-backed mice of the genus *Clethrionomys* also have three representative species that nearly if not quite meet, but without intergrading. *C. dawsoni* is the northwestern form that ranges from Alaska and Yukon south to northern British Columbia and eastward in the north to the Perry River and northern Manitoba. Just south of it, but with a wider range, from Nova Scotia to northern British Columbia and southward lives the closely related *C. gapperi*. There is some habitat difference in part: *C. dawsoni* lives in the Barrens and the forests, while *C. gapperi* lives only in the forests. A further species, *C. wrangeli*, of northeastern British Columbia and nearby islands, related to *dawsoni*, recalls the case of the Queen Charlotte Island caribou (*see* p. 34).

(e) East and west refugia in the Arctic

The east–west division of an aquatic arctic mammal, comparable to that of the black- and the white-bellied brant (genus *Branta*) and the Atlantic and the Pacific eider (genus *Somateria*) (Rand, 1948, p. 316), is shown by the Atlantic and the Pacific walrus (*Odobenus rosmarus* and *Odobenus divergens*).

The former, of the Eastern Arctic, ranges northward to the arctic islands, but only rarely west of Barrow Strait, Somerset Island, and Fury and Hecla Strait; the Pacific walrus ranges commonly to Point Barrow, but only casually farther east.   Apparently, present-day ice conditions keep them apart.   During the Ice Age, they were even more isolated.

(f) Several refugia, including one on the arctic islands

The most complex case has been left to the last.   The relationships of the various forms of caribou (genus *Rangifer*) are still far from clear.   They have been grouped into five species by Anderson (1946, pp. 178–81), but there seem to be two main types: a southern woodland type, large, with smaller, flattened and palmate antlers; and a northern Barren-Ground type, variable in size but with larger, more slender, little flattened antlers.   In the northern Manitoba–Alberta–southern Mackenzie area these meet as species, with, at least during the winter season, some overlap of range when the northern form moves south.   However, in the northwest (Alaska–Yukon–British Columbia) there are forms (*osborni*, *fortidens*) that seem to be intermediate and to connect the two types, giving a circular chain of subspecies, with the ends overlapping as species.   Within the Barren-Ground group there are also several distinct forms: *pearyi* of the northern arctic islands; *groenlandicus* of west Greenland; *arcticus* of the southern arctic islands and the mainland of the Northwest Territories; the larger, northern Yukon–Alaska forms (*stonei*, etc.); and out-lying populations in addition to the above mentioned *osborni* of southern Yukon and *fortidens* of the Rocky Mountains, of *montanus* in the Selkirk Range of British Columbia, *dawsoni* in the Queen Charlotte Islands, and *caboti* in northern Labrador.

The present distribution and manner of meeting again strongly suggests that during glaciation the caribou population was fragmented, and parts sur-vived in refugia southeast of the ice (woodland type); southwest of the ice in perhaps three refugia (the mountain, Rocky mountain, and Queen Charlotte Island caribou: *montanus*, *fortidens*, and *dawsoni*) of an intermediate type; in the Bering Sea area (large Barren Ground animals of *stonei* type), and in northern refugia (*arcticus*, *pearyi*, and *groenlandicus*).

There are certain parallels between this and the distribution of the Canada geese and the gulls of the Herring–Iceland gull complex (Rand, 1948, pp. 315–6), even to the circular chain of subspecies that overlap as species.

These examples of groups of closely related species in which the elements of each group meet sharply when there are no evident geographical barriers, are interpreted as effects of the Ice Age.   The glaciers of the Ice Age rendered uninhabitable the vast area of northern North America.   The mammal fauna that presumably had inhabited this area survived only on the fringes of the ice, in refugia.   Here in this isolation each part of the original species went its way toward the species state.   With the melting of the ice, what is now Canada and Alaska became available and suitable for mammal occupancy. The mammals spread into it from their refugia.   Some travelled faster than

others, notably those from the southeast. Some were more adaptable than others, notably those that spread from the Bering Sea area of mountains and tundra onto the main Barrens of Canada. Some spread but little, notably those of the Pacific coast. A difference in habitat tolerance is shown from group to group: the Dawson red-backed mouse spread south and eastward to meet its southeastern relative in the forest, while the meadow mouse spread north of the forest onto the Barrens, and the tundra mouse of the Barrens kept still farther north.

In only one case, the arctic and the woodland caribou, do we have tentative evidence of a circular series of subspecies; there are indications that the two forms behave as species to each other, while related forms, in other areas, suggest that they are connected by a series of intergrades.

It appears that these forms have evolved to the point where they do not interbreed but each maintains its entity when they meet. It also appears that their ways of life are so similar that they are unable to live together in the same area. Their ranges being mutually exclusive, they are barriers to each other. Though they have gone part of the way to being species, they still retain the subspecific character of having their ranges mutually exclusive. In some cases some intergradation or hybridization may be found to occur where they meet, but this will probably be sporadic, or cover only a narrow zone. In the practice of classifying these forms, it may be found advisable to group some of them together in species with wider limits. Be that as it may, a proper interpretation seems to be to regard them as emergent species. The meeting between them seems to be a secondary one. This gives us a clue as to how some species have evolved on continental areas.

The effects of glaciation on speciation are not necessarily confined to the extreme northern part of the North American continent, but I have considered only the elements whose range does include the north. I have moreover discussed only one aspect of the speciation problem, that in which the forms are closely related geographical-representative species.

It is probable that the various glacial and interglacial periods each had their effect: some early effects may have been intensified, cancelled, or complicated by later ones. Some well established species that now live together may have had their origin in an early glacial period; some obvious subspecies may have had their limits influenced by the latest glaciation. Then, too, there is the possibility of Asiatic influence, through an immigration of forms from Asia during the period covered by the various glacial and interglacial periods. For the present it seems advisable to leave this for further discussion.

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REMARKS ON THE REPRODUCTION, SEX RATIO, AND LIFE EXPECTANCY OF THE VARYING LEMMING, *DICROSTONYX GROENLANDICUS*, IN NATURE AND CAPTIVITY

T. H. Manning

In 1949 a colony was started in Ottawa from 16 Greenland Varying Lemming, *Dicrostonyx groenlandicus groenlandicus*, which had been captured at Igloolik on 14 September 1949 (*see* Manning, 1950). Three females and 3 males bred, and the colony reached a peak of 76 in April 1951, but declined during the following summer. A single female Mackenzie Varying Lemming, *D. g. kilangmiutak*, from Tuktoyaktuk, was added to the colony that fall, and mated with one of the *D. g. groenlandicus* males to produce six litters, after which most of the colony consisted of intergrades. There was a considerable decline in numbers during the summer of 1952, and no attempt was made to rebuild the colony the next winter. By September 1953 only one lemming was left.

The captive colony was established primarily to obtain growth data for the more accurate aging of specimens collected in the field, and no deliberate experiments were made to determine reproduction rates under specific conditions. However, owing to scarcity of published information on this aspect of the biology of the Varying Lemming, it appeared worth analysing the records of the colony and comparing them with field observations as well as with some of the more detailed work which has been done on related genera. In view of the small numbers involved and the lack of adequately controlled conditions, the results should be treated with caution, particularly as the continuity of the records was broken each summer when I was absent in the Arctic[1]. The need for further experiments and field observations may also be stressed.

Age of sexual maturity

Throughout the life of the colony there was a shortage of males, and it was felt, possibly erroneously, that the best way to build up the population was to mate the available males with females of mature age, particularly those

Table 1. Distribution of young in litters

litter size or embryo count	1	2	3	4	5	6	7	8	11	Total no. of litters or pregnant ♀♀	Mean no. per litter or pregnant ♀♀ ± S.E.	Standard deviation $\sqrt{\dfrac{\Sigma(fd^2)}{N}}$
Frequency in each group of litters counted within 24 hours of birth. Live and dead young included	7	12	11	8	14	3	1			56	3.41 ± .21	1.57
Frequency in each group of litters first counted at an average of 4 days after birth	8	7	5	5	2					27	2.48 ± .25	1.29
Frequency in each group of litters from 4 feral-born ♀♀		3(5)	5(5)	4(4)	7(5)	2(2)				21	3.98 ± .27	1.23
Frequency in each group of litters born to 9 ♀♀ when known to be under 250 days old	3(4)	2(1)	3(6)	7(6)	5(5)	2	1(1)			23	3.80 ± .34	1.61
Frequency in each group of litters born to 7 ♀♀ when known to be over 250 days old	4(10)	14(13)	8(4)	2(2)	6(5)	1(1)				35	2.83 ± .23	1.36
Frequency in each group of litters counted within 24 hours of birth) in which all deaths were recorded until after weaning	5	11	9	7	11	3	1			47	3.45 ± .23	1.57
Frequency in each group of litters recorded in line 6 when recounted on 4th day	6	12	7	5	12	2				44	3.25 ± .23	1.54
Frequency of embryo and placental scar counts in feral ♀♀		1	2	5	11	3	4	3	1	30	5.47 ± .33	1.80
Frequency in each group of feral litters	2	1	6	6	1	2	1			19	3.68 ± .35	1.52

In lines 3, 4, and 5 the actual counts made are given in brackets; the other figures show the size and frequency after one young has been added to adjust for deaths prior to counting in those litters not counted until 24 hours or more after birth (*see* line 2). In calculating the means for these three lines the more accurate figure of .93 (the difference between the means of lines 1 and 2) has been used.

There do not appear to be many records of embryo or nestling counts of Varying Lemming in the literature. The figures in lines 8 and 9 are derived as follows: Ross (1835, p. xiv), March, 4 embryos, July, 6 nestlings; Preble (1902) [August, 3, 3 nestlings, 3 embryos]. Actually Preble says, "Three young at a birth seems to be the usual number. Every litter we found consisted of three, and in each pregnant female we secured were three embryos". MacFarlane (1908), June, 5, 5 embryos; Allen (1919, pp. 522, 523, 537), June, 4, 5, 8, 7, 11 embryos, July, 5 embryos, August, 4 nestlings; Sutton and Hamilton (1932), January–April, 5 nestlings, 2, 5, 5, 7 embryos; Shelford (1943), July, 6 nestlings; Strecker and Morrison (1952), August, 4 nestlings; Hanson (unpubl.), July, 6, 8, 5 embryos, 5, 4 placental scars; Manning and Macpherson (1949, Field Notes), August, 3, 5 nestlings, Manning (1953, Field Notes), June, 7, 7, 8, 6, 5 embryos, July, 5 embryos, August, 4, 4 nestlings. MacDonald (1949, Field Notes), 4, 4 embryos, July, 2, 3, 1 nestlings, August, 4 nestlings, September, 1 nestling; MacDonald (1951, Field Notes), July, 4 nestlings; Handley (1949, Field Notes), June, 6 embryos, August, 5 embryos, 3, 7 nestlings. Additional more generalized information is also sometimes given. Thus Shelford (1943) says that 5 to 8 young were reported by Twomey in 1933, and 4 to 6 in both years of abundance. Ross (1835) gives the number of young as 4 to 8. Freuchen (Degerböl and Freuchen, 1935) found 8 fœtuses in a female in July 1922, but remarks that other females had not nearly so many. Armstrong (1857, p. 558) says, "they generally bring forth from two to six at a birth; in a few instances as many as eight or nine", and Feilden (1877) that the young number 3 to 5. See also Degerböl and Möhl-Hansen (1943).

which had already bred but had lost their first mate.[1] However, since full-grown females had a tendency to kill younger lemmings, the males were seldom mated until 80 to 100 days old. There were therefore few opportunities for early breeding, but in spite of this one female produced a litter at 84 days of age, one male sired a litter at 46 days, and another at 61 days (allowing 20 days as the gestation period).

Litter size

Comparison of counts at birth and later. The distribution of young in 83 litters counted between February 1950 and April 1952 is given in Table 1.

[1]One reason for this belief was that the three pairs of original captives, which were probably a month to 6 weeks old when caught, did not produce young for the first 5, 6, and 7 months respectively. It is now of interest to speculate if there is a connection between this delay and the period (near the peak or possibly the start of decline of the population cycle) at which they were captured. The single female, taken at Tuktoyaktuk in 1951 when the cycle was near a low point, had its first litter within 5 weeks of being mated, but there was little sign of an increase in the Tuktoyaktuk area the following year.

Fifty-six of these counts were made within 24 hours (usually within 12 hours) of birth, and have been assumed to represent the actual number born alive or dead. Records of deaths in 47 of these litters, selected at random, were kept until after weaning. Their mean size at the first count was 3.45. All the 4 young of one litter were dead when first found, and all in two of the remaining litters were dead by the second day. By the fourth day after birth, the mean size of the surviving 44 litters had been reduced by natural deaths to 3.25, and by the eighth day to 3.20 young.

Ranson (1941, p. 55) reported a reduction of .52 young per litter in 411 litters of captive Field Voles, *Microtus agrestis*, kept under optimum conditions, between birth and weaning at 14 days. He excluded from his first calculations young found dead at the first count, but included litters completely exterminated later. A comparable figure for the 46 lemming litters which had live young on the first day is .41 young per litter, a difference of only .11 from Ranson's figure. The mean number of young in the 44 lemming litters surviving on the fourteenth day was 3.07 ± .24.

Twenty-seven litters not found within the first 24 hours after birth were counted at varying intervals thereafter, an average being at about 4 days. The mean size of these litters was then 2.48, which is .77 ± .34 less than the mean size on the fourth day of the 47 litters for which detailed records were kept from birth. Since most of the 27 late counts were made during the summer when I was away, it is possible that either some of the young were missed in the counts or the litter size was affected by the higher temperature or other changed conditions.

Table 2. Number of young per litter according to litter sequence in 69 litters

Litter sequence	1	2	3	4	5	6	7	8	9
No. of litters recorded within 24 hours of birth + no. recorded later	12+6	10+5	7+4	3+3	5+0	5+0	1+2	1+2	1+2
Mean no. of young in litters	3.42	3.50	3.50	3.30	3.75	5.40	3.28	3.94	4.61

In calculating the mean number of young in the litters, .93 has been added to those litters which were not recorded within 24 hours of birth. This figure is the difference between the mean of those counted within 24 hours of birth and the mean of those not counted until later (*see* Table 1, lines 1 and 2), and here assumed to be due to death before counting or to the different conditions under which the lemmings were living when most of the late counts were made.

Effect of age of mother on litter size. Table 2 shows that there was no obvious correlation between litter size and litter sequence in the captive lemming for the first 9 litters.[1] However, the material is obviously heterogeneous since some of the mothers were feral-born and some captive-born. Also, there was a great disparity in age of the mothers, and, perhaps more important, the earlier litters were heavily weighted by mothers which died young and may therefore have been constitutionally unsound. The large mean size of the sixth litters is noteworthy, but since only 5 litters are involved, it is probably due to chance.

Table 4, which groups the litters according to the age of the mother, indicates that there was a gradual decline in the average size of litters born to mothers after the 101–150 age group, using a 25-day grouping for the

[1]Only 2 females had more than 9 litters. The details of these are shown in Table 3.

Table 3. Number of young and interval in days between litters for the two pairs producing the largest number of litters

Pair A		Pair B	
No. young in litters	Interval in days from birth of preceding litter	No. young in litters	Interval in days from birth of preceding litter
2*		5*	
4	21½–24½	4*	39 approx.
4	23¼–24½	3*	27 "
5	21¼–22¼	3	19 "
6	26 –27	2	21 "
6	21¼–22¼	5	21 "
4*	22 approx.	2	23 –24
3*	23 "	3	20½–21½
2*	20 "	5	20 –21
4*	22 "	3	25 approx.
2	58 "	1	22 "
2	22 –22½	1	20 –22
5	17½–18½	2	35 –37
		1*	24 approx.
		1*	18 "
		1*	24 "

Both sets of parents were kept paired. Pair A were at least half-grown when captured at Igloolik on 14 September 1949. The first litter was born 158 days later when the estimated age of the parents was 190 days. Four hundred and fifty-nine days after capture, the female was found dead after having given birth, probably prematurely, to one of its 5 embryos. She had produced 13 litters in 302 days at an average interval of 25.2 days between litters. The mean litter size was 3.77, or 4.12 if corrected for the 5 (starred) litters which were not found within 24 hours of birth. The male died soon after siring its last litter, about 456 days after capture.

Pair B were unrelated first generation captives. The female was 158 days old when the first litter was born, and 520 days old at the birth of her last litter. She died on the 667th day after producing 16 litters in 362 days with an average interval of 24.2 days between litters. The male was about 110 days old at the birth of the first litter, sired its last litter with another female at about 661 days, and died at 748 days. The mean litter size was 2.63, or 2.97 if corrected for the 6 (starred) litters not found within 24 hours of birth.

Table 4. Mean size of 58 litters born to mothers in different age groups

Age in days	51–100	101–150	151–200	201–250	251–300	301–350	351–400	401–450	451–500	501–555
No. of litters in each age group	1+0	8+3	4+3	2+2	6+1	7+3	5+3	3+0	1+4	0+2
Mean size of litters from 13 ♀♀ of known age	4.0	4.53	3.11	2.96	2.99	2.98	2.85	2.33	2.74	2.43

The first figure in each age group shows the number of litters which were found within 24 hours of birth; the second figure, those which were not counted until later. To obtain the mean litter size, .93 young was added to the size of each of the latter. This figure is the difference between the mean of those counted within 24 hours of birth and the mean of those not counted until later (*see* Table 1, lines 1 and 2).

mother's age, it was found that there was a statistically significant negative correlation ($r = -.33$, $P < .02$) between the mother's age from 100 days onward and litter size. The coefficient of regression was $.10 \pm .04$. Leslie and Ranson (1940, p. 50), grouping their data in 8-week periods, found the litter size of captive Field Voles, *M. agrestis*, increased with the advancing age of the mother to a maximum in the 20 (16–24)-week period before it gradually declined. Since the mid-point of the group with the greatest litter size in the lemmings is only 14 days short of the mid-point of the group with the greatest litter size in the voles, and since the two species appear to reach sexual maturity at about the same age (*see* Leslie and Ranson, 1940, p. 34 for data on sexual maturity in *M. agrestis*) it is probable that the absence of small early litters in the lemmings is caused by the artificially late date at which they were mated.[1] The age of the mothers at the birth of the first litter, shown

[1]However, in the rat, *Rattus rattus*, first litters average smaller than second even when the female is mated late (Asdell *et al.*, 1941).

by Asdell *et al.* (1941) to affect the mean size of litters produced by rats, did not produce a demonstrable effect in the lemmings. The small negative, non-significant correlation ($r = -.16$, $P > .1$) between the age of the mothers at birth of their first litters and the average size of their subsequent litters, was due to the average age of the mothers at birth of all litters.

Since there appears to be a difference in the size of litters produced by the younger and older mothers, it is possible that litters born after a cyclic decline in lemming numbers, during which it seems probable that few if any young are born,[1] would be smaller than at other periods because of the comparatively old age of the breeding population. Thus recovery would be delayed for a generation.

Comparison of embryos and nestling numbers from field counts. Turning to the figures in Table 1 (lines 8 and 9) for the embryo and litter counts made in the field, it will be seen that the mean number of young per litter has dropped from 5.47 in the embryo counts, which, being mostly casual observations, probably included few records for the earlier stages of development, to 3.68 in the litter counts, which may be assumed to have been made about a mean of 8 days after birth. Ranson (1941) palpated 382 pregnant captive Field Voles, *M. agrestis*, about the fourteenth day of pregnancy to obtain an estimated mean of 3.91 embryos per female. These females produced 340 litters[2] with a mean number of 3.64 young, found alive or dead, showing a wastage of .27 per litter during the latter part of pregnancy. If a similar wastage is assumed in the lemming during the prenatal period and added to the figure, .25, obtained for wastage in 44 litters of lemming between birth and the eighth day, the total expected wastage between the average period of the feral lemming count and the average period of the litter counts would be .52. But since there are more young in the larger litters of the feral lemming, more deaths per litter are to be expected, and the figure for the mean size of the litters must be adjusted accordingly. The adjusted figure will be $\frac{5.47}{3.91} \times .27 + \frac{3.68}{3.20} \times .25 = .38 + .29 = .67.$

This expected wastage is distinctly smaller than that obtained from the records of feral embryo and nestling counts, namely, 1.79 young per litter.

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[1]There is as yet no good evidence for this in the Varying Lemming. However, it is my impression that no embryos were found in 23 females, over 125 mm. in total length, collected in northern Foxe Basin in late August and early September 1939, when the cycle was thought to have passed the peak, but the negative evidence was not recorded, and it is probable that all the females were not examined internally. Mammary tissue was present in one female, and a number of young in the 3- to 6-week class were obtained. In June 1952, on southern Banks Island when lemming were increasing, 5 of the 13 females over 125 mm. in total length were pregnant. The smallest female measured 128 mm. and contained 6 embryos. One only, taken July 30, of the 12 females over 125 mm. collected on northern Banks Island in late July and August was pregnant, but recently weaned young were common in the latter month. None of the 59 Brown Lemmings, *Lemmus trimucronatus*, examined by Rausch (1950, p. 176) in the Point Barrow region prior to and during the cyclic decline in 1949 was pregnant or had placental scars, although a few showed perforate vaginae.

[2]We are not here concerned with the 42 palpated pregnancies which resulted in no young found alive or dead.

The difference may or may not be significant. The standard errors have not been calculated since the data for expected wastage are heterogeneous, and seasonal or more probably cyclic variations in litter size may have biased the feral counts, as the number of litter and embryo counts of individual observers in single seasons are not always well balanced. It is clearly desirable to obtain additional data and look more closely for possible causes of wastage in feral litters. Under field conditions there is of course a considerable wastage of whole litters caused directly by predation on the litters or indirectly by predation on the mother, but there is no apparent reason for a greater wastage within feral than within captive litters.

Comparison of litter size in feral and captive lemmings. If the best available corrections, .38 and .29, are respectively subtracted from and added to the field counts of lemming embryos and litters and an unweighted mean of the result taken, a figure of 4.53 ± .28 is obtained as an estimate of the litter size at birth under natural conditions. The difference between this and the mean for the 56 captive litters counted at birth (Table 1) is 1.12 ± .35, which is probably significant even though the corrections used are also subject to error.

A number of causes may have contributed to a reduced litter size in the captives, although no single one appears sufficient to account for the whole difference. As shown above, some reduction may have been due to the advanced age of the mothers when most of the litters were born, but on the other hand, the small litters expected from females under 100 days are likely to have reduced the mean litter size of the feral animals.

The inbreeding inevitable in a colony which was derived from 4 feral females and 3 males only may have tended to reduce litter size, and Table 1 shows that the mean size of litters born to the 4 feral females was slightly larger than those of the second and subsequent generations, in spite of the average age of the former at the birth of their litters being 290 days when based on a conservative estimate of their age when captured. Of the 8 Varying Lemming litters recorded by Degerbøl and Møhl-Hansen (1943, p. 10), the 5 born in captivity of feral parents had a mean size of 4.40, while the 3 born to their offspring had a smaller mean, 3.67. In both instances the litters may originally have been larger, as they were not counted until some days after birth.

The experiments of Baker and Ranson (1932, and 1933) with the Field Vole, *M. agrestis*, suggest that lowering the temperature or decreasing the period of light does not reduce litter size, although it does reduce fertility of the female. It would be surprising if a comparable reduction in daily exposure to light would cause a similar loss of fertility in the Varying Lemming (cf. Hamilton, 1941, p. 21) which are known to breed during the arctic winter (Ross, 1835; Sutton and Hamilton, 1932), while Field Voles apparently do not breed in the winter even in Britain (Asdell, 1946; Chitty, 1952).

Most of the paired captive lemmings were kept at about 60°F during the winter, and light was supplied for an average of 14 hours a day by a 60-watt bulb. One pair was exposed to full room daylight, including some sun, plus

electric light until 11 p.m. A few during one winter were given no light except a little diffuse daylight and occasional distant electric light for not more than 3 hours a day. A few pairs were kept outside in cages with a minimum of nest material throughout the winter, and were therefore perhaps subjected to more severe conditions than they would encounter under the snow in the Arctic. Only one of the pairs kept outside produced young: a litter of 4 on February 28, and one of 5 on April 5. The number of pairs under the varied conditions was not sufficient to draw any definite conclusions, but none of the conditions had any obvious effect on litter size. It is still possible that 24 hours of light, which is normal for lemmings under natural spring and summer conditions, would increase either fertility or litter size, although it must be remembered that feral lemmings spend a considerable period below ground, and there was some indication that the captive lemmings exposed to the most light were the most aggressive and irritable. It is also possible that 60°F is above the optimum temperature for lemmings, and that a temperature nearer that of summer arctic conditions would increase litter size and/or fertility. The apparent failure of the captive lemmings to produce as large litters in the summer as in the winter may have been an effect of temperature.

The staple winter food of the captive lemmings consisted of rolled oats to which had been added wheat-germ oil (vitamin E), orange and grapefruit peel, some green vegetable material, occasional carrots, and usually some green bark. In summer the green food and carrots were increased, and the wheat-germ oil was often omitted, but fresh grass was added in most cases. There was almost always an excess of food in the runs. Water was also supplied, and contrary to the reports of Degerbøl and Møhl-Hansen (1943, p. 37) and Strecker and Morrison (1952, p. 182), it was frequently drunk. Naturally the food differed greatly from that eaten by lemmings in their natural habitat, but there does not appear to be any obvious deficiency.[1] Also, Bodenheimer (1949, p. 45) gives evidence of special foods which influence fertility, at least in species with the rabbit–ferret type of oestrus cycle, while the experiment of Baker and Ranson (1933) on the effect of winter and summer foods in *M. agrestis* gave the unexpected result of a considerable excess in the total number of young born to the mice supplied with winter food over those supplied with summer food. The increase amounted to .83 young per litter when pregnancies resulting in the absorption of all young are included, but a reduction of .18 when such pregnancies are excluded.

It is not known if there is any variation in the average size of summer and winter litters of feral lemmings, or even if they breed every winter. A suggestion of the possible behaviour may be obtained from Hamilton (1937), who found that the Meadow Vole, *Microtus pennsylvanicus*, in central New

[1]It was noted that the second and third generation of captives were in general less friendly than the feral-born individuals, and much more inclined to fight with each other. Two strange adults of the same sex could seldom be put together without one being killed, but the original group was brought to Ottawa in one box and lived together for over 6 weeks with no serious fighting. It is very tentatively suggested that the cause of this apparent difference may have been a dietary deficiency.

York state bred in winter only when the population was near peak numbers. Even then, the number of embryos per pregnant female was considerably fewer than in summer. There was also a reduction in embryo numbers following and preceding the winter non-breeding period of other years. Hamilton also shows that the mean number of embryos per pregnancy during the summer preceding the cyclic maximum was distinctly higher than in other years. Confirmation of this for another species is given by Bodenheimer and Sulman (1946), who state that the litter size of *Microtus guentheri* increases from the normal 3–8 to 6–12 in the initial phase of vole outbreaks in Palestine, possibly because of seasonal and cyclic fluctuation in a plant gonadotropin. Shelford (1943) suggested an increase in litter size during the up-swing of the lemming cycle, but as yet there is little direct evidence for or against this, although it may be noted that my Banks Island embryo counts in the spring of 1953, when the lemming were first recovering from a crash two years earlier, are higher than those of Handley and MacDonald for the summer of 1949 (Table 1), when the latter believed lemming to be at a peak in Prince Patrick Island. Any factor causing larger litters at certain periods of the cycle might account in part for the apparent difference between the mean size of the feral and captive litters.

Gestation period and litter frequency

The females of two pairs which had been breeding regularly were isolated and their respective mates later introduced into their runs for 24 hours: in the first pair, 14 days after the birth of the preceding litter of one young which was weaned on that day, and in the second, two days after the birth of one young which was also weaned about the fourteenth day. The minimum possible gestation period in both tests was 19 days, and the maximum, 20 days 10 hours in the first (when one young was born) and 21 days in the second (when 6 young were born). When, as in most cases, the pairs were left unbroken, re-fertilization was normally effected at post-partum oestrus (*see* Table 5). Since there is a significant correlation ($r = .52$, P about .02)[1] between litter size and interval to birth of next litter for the 20 litters of Table 5 with intervals between 20 and 26½ days, the intervals of 22 to 26½ days are probably occasioned by delayed implantation caused by lactation, as has been observed in the related genus *Clethrionomys* (Brambell and Rowlands, 1936), though not in *M. pennsylvanicus* (Hamilton, 1941). The 36½-day interval could be due to the same cause, as the preceding litter of 5 young was not removed from the parents until they were 20 days old. The remaining three long intervals were probably due to fertilization at a post-lactation oestrus after failure at post-partum oestrus, since there were only 1, 1, 2 young respectively in the preceding litters, and the single young born prior to the 35-day interval died when it was 12 days old. In five instances involving 8 litters with mean size of 4.12 young per litter, Degerbøl and Møhl-Hansen (1943, p. 10) reported the interval between litters to be about a month, but the young were not always found until some days after birth.

[1]The regression of interval on litter size is 2.2 ± 0.8 days.

Table 5. Intervals between litters for pairs kept mated

Interval (max. error 1 day) between litters in days	20	20½	21	21½	22	22½	23	23½	24	24½	..26½	..35	..36	..36½	..42
No. litters	2	2	5	1	6	–	–	2	–	1	1	1	1	1	1
Mean no. young at birth in litter preceding interval	2.5		2.2		4.3			4.5		3	5	1	1	5	2
Mean no. young in litter following interval	4.0		2.8		3.8			3.0		1	6	1	2	5	2

The young were usually weaned between the 14th and 18th day. Two died in one litter of 4 young about the third day. The interval between it and the following litter was 21½ days. None of the other litters lost more than one young before the 14th day.

Hamilton (1949) points out that copulation immediately after parturition is not merely a response to captivity, but occurs naturally in several mammals, including the Red-backed Vole, *Clethrionomys gapperi*, and the Muskrat, *Ondatra zibethica*. He (1937) also found up to 83.3 per cent of nursing *M. pennsylvanicus* pregnant at a period of maximum production, while Brambell and Rowlands (1936) concluded that most female Bank Voles, *Clethrionomys glareolus*, must become pregnant again at post-partum oestrus. In the Varying Lemming I know of only two records of pregnant nursing females. Preble (1902) reports a female near Churchill which was suckling 3 young and contained 3 embryos, and I recorded one on Banks Island with degenerating mammary tissue and 7 small embryos. Handley (Field Notes) found a nest at Mould Bay which contained young from two litters of different ages. Further careful observations are desirable, and will probably show that at certain stages in the population cycle pregnant nursing females are not uncommon.

Sex ratios

The pooled specimens of the five collectors shown in Table 6 were obtained in northern Canada without selection for sex. In a total of 410 *D. groenlandicus* and 26 *D. hudsonius*, 50 ± 2.4 per cent, were male. Of course all that is here proved is that half the sum of the number caught by trap (about two-thirds) and by hand (about one-third) were male. The actual proportion of males in the population can only be assumed, as one of the sexes may be more susceptible to being trapped or dug out from burrows. When the major collections are considered separately, it is seen that the one from Piling has a chi-square value which is surely too high to be consistent with the hypothesis of a 50 per cent male population, while there are two others, from southern Banks Island and from Mould Bay, which have probably inconsistent values. The Piling collection differs from the others, except perhaps the Igloolik, in that it was obtained from a restricted area probably under a quarter of a mile square. It would appear that either there was a local concentration of females, or the females, which were apparently not at that time breeding, were more susceptible to traps. The other two collections from Baffin Island or the nearby islands of Foxe Basin including Igloolik, which were taken about the same period and, it is thought, at about the same stage of the cycle, do not show the same discrepancy, and are, in fact, the most consistent with the hypothesis of a 50 per cent male population. It is true that these two

Table 6. Sex ratios from random counts of 436 feral and 119 captive Varying Lemming

	Collector	No. specimens	Per cent ♂ ± σ	Adjusted chi-sq.
Piling, Baffin Id., 31 Aug.–4 Sept. 1949	A. H. Macpherson T. H. Manning	30	23.3 ±7.7	7.5
Igloolik Id., Foxe Basin, 14 Sept. 1949	T. H. Manning	31	45.2 ±8.9	0.1
Other Baffin Id. and Foxe Basin areas, chiefly C. Dorset, 12 Aug.– 11 Sept. 1949	T. H. Manning	38	55.3 ±8.1	0.1
S. Banks Id., 6 June 1953	E. O. Höhn T. H. Manning	54	63.0 ±6.6	3.1
N. Banks Id., 5 July–28 Aug. 1953	T. H. Manning	43	39.6 ±7.5	1.5
Mould Bay, Prince Patrick Id., 26 Apr.–5 Aug. 1949	C. O. Handley S. D. MacDonald	166	57.8 ±3.8	3.8
All above collections and some smaller collections[1]		436	50.0 ±2.4	–
Captive lemmings, Feb. 1950–Apr. 1952		119	31.0 ±4.2	16.3

The standard deviations of the percentages are based on the relative proportions of the sexes in the respective samples. The chi-square values are based on the hypothesis of a population equally divided between the sexes.

Specimens from Igloolik and Cape Dorset were all hand-caught by digging burrows or searching under stones. Nearly all those from Piling and Banks Island were caught in baited traps, usually placed in runways. The Prince Patrick Island specimens were partly trapped and partly dug out.

[1] These latter were taken between 1944 and 1953 by S. D. MacDonald, A. H. Macpherson, and T. H. Manning and include 26 *D. hudsonius* from the east side of Hudson Bay.

collections were taken principally by hand, but the southern Banks Island collection, which was nearly all trapped, was 63 per cent male, so that it cannot be said that the females are necessarily more susceptible to traps. Hantzsch (1913, p. 150) records an even greater disproportion in favour of the males at Blacklead Island in the spring of 1909 when only one out of 30 specimens was female. It appears, therefore, that whereas the total lemming population is approximately equally divided between males and females, local concentrations of either sex may occur at certain places and seasons, or alternatively, one or other sex may at times be more easily taken, especially by trapping.

The captive lemmings were usually sexed between the ages of 25 and 60 days. In their case the proportion of males is presumably representative of the population of the colony, although it is thought that males had a shorter life expectancy, so that the proportion born may have been distinctly higher than the 31 per cent of Table 6, but probably significantly less than 50 per cent. It is tentatively suggested that one or more of the small number of feral lemming contributing to the colony may have had an inheritable tendency to produce more than the normal proportion of females. Although less pronounced, this might be comparable to the genetic condition known as "sex-ratio" in the fruit fly, *Drosophila* (Wallace, 1948).

Care of young

Both sexes of the segregated captive pairs tended the young. The male was often almost as assiduous as the female in carrying the young back to the nest when they were old enough to crawl out. Both sexes would remove the young from a disturbed nest. MacDonald found two nests at Mould Bay containing a pair of adults and half-grown young, which suggests that even under natural conditions lemmings remain paired after the birth of the young.

Life expectancy and disease

There is no direct evidence of the normal age limit of the Varying Lemming in their natural habitat, but in some other small microtine rodents (e.g., *M. agrestis* (Chitty, 1952), *C. glareolus* (Brambell and Rowlands, 1930)) survival through a second winter is exceptional, if indeed it occurs at all.

In captivity, the mean life span of 87 live-born Varying Lemming calculated from the grouped data of Table 7 was 105 days, or 143 days if calculated from the number surviving on the twentieth day. The latter figure may be compared with 34.57 weeks (242 days) given by Leslie and Ranson (1940, p. 50) for 144 Field Voles observed from the age of 3 weeks.

Table 7. Deaths of 87 captive lemmings recorded by age groups

	20-day periods					50-day periods								
Age in days, mid periods	10	30	50	70	90	125	175	225	275	325	375	425	450 upward
No. of deaths	25	11	10	7	6	10	5	1	4	3	2	1	2

The two lemmings living beyond 450 days died respectively on their 667th ($\female$) and 748th ($\male$) day.

Table 7 was included with some misgivings. It is inevitably biased because the greatest number of births occurred in the late winter and early spring, whereas the greatest number of deaths occurred during the summer when records were not kept. Furthermore, the number of natural deaths, the only ones included in the table, in middle and old age were disproportionately reduced by accidental deaths, by escapes (about half the lemmings were kept in boxes or open runs), and by gifts of animals for experimental or other purposes, so that the 87 deaths recorded are in effect selected individuals from the 255 births which were noted. The maximum life span of the lemmings recorded in Table 7, 748 and 667 days for a male and female respectively, is very similar to that for Leslie and Ranson's voles (1940), but in addition, two females, which had never bred and were kept as pets for the latter part of their lives by Mr. and Mrs. G. W. Rowley, reached the age of about 2½ years and 3 years and 2 months respectively.

The oldest female to bear young was aged 555 days at the time of its last litter, and the oldest male was 661 days old when it sired its last litter.

The cause of death of most of the younger captive lemmings is unknown, but it was noted that several might die within a period of a few days, and there then might be two weeks or more with no deaths. Sometimes the lemmings became thin before dying; at other times they were fat and apparently healthy until about 24 hours before death. About 8 lemmings which died from unknown causes were sent to the Animal Diseases Research Institute, Hull, P.Q., for autopsy, but the cause of death could not be determined. One lemming died from cancer (Rowley, 1953).

The original captives were brought to Ottawa with 7 Brown Lemming, *Lemmus trimucronatus*, with which they occasionally had direct contact. Six of the Brown Lemming died shortly after arrival, and *Listeria monocytogenes* was isolated from the 4 sent to the Animal Diseases Research Institute (Plummer and Byrne, 1950), but the Varying Lemming were apparently not affected.

Summary

The mean number of young born, alive or dead, in 56 captive litters counted within 24 hours of birth was 3.41 ± .21. Records for 47 litters were kept until after weaning. On the fourteenth day, 44 of these had some surviving young, and their mean litter size was then 3.07 ± .24.

There was a significant correlation between the age of the mother when over 100 days and litter size: r = −.33, P < .02.

The mean of 30 feral embryo and placental scar counts was 5.47 ± .33, the mean of 19 feral litter counts, 3.68 ± .35. The apparent wastage, therefore, was 1.79 young per litter against an estimated wastage in captive litters of .67.

The mean size at birth of 49 feral litters was estimated at 4.53 ± .28; the difference between this and the mean size of 56 captive litters was 1.12 ± .35 young. Possible causes are discussed.

The normal gestation period is believed to be between 19 and 21 days. When pairs were left mated, conception apparently occurred usually at post-partum oestrus, but the interval between litters was sometimes increased to 26½, and perhaps in one case to 36½ days. There was a significant positive correlation (r = .52, P about .02) between this interval and the size of the preceding litter, presumably owing to delayed implantation caused by lactation.

Fifty ± 2.4 per cent of 410 *Dicrostonyx groenlandicus* plus 26 *D. hudsonius* taken in northern Canada were males, but some collections from localized areas showed a significant variation. Only 31 ± 4.2 per cent of the captive lemmings, usually sexed between the ages of 25 and 60 days, were males.

The mean life span of 87 live-born captive lemmings dying from natural or unknown causes was 105 days, but this figure is probably biased by interruptions in the records and therefore too low. The oldest male died on its 748th day, and the oldest female at about 3 years 2 months. The oldest male sired its last litter about the 661st day, and the oldest female to bear young was aged 555 days. One lemming died of cancer; the cause of death in other cases was not determined.

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INSTITUTE NEWS

Director of the Montreal Office

As announced in the December 1953 number of the Journal, the resignation of Mr. P. D. Baird, Director of the Montreal Office, as from July 1954, was accepted with much regret at the Executive Meeting on 16 November 1953. Mr. Baird was appointed the first director of the Montreal Office in 1947, and left Canada, with his family, on July 6 to take up his new appointment in the Department of Geography, University of Aberdeen, Scotland. Mr. Baird, who had carried out many previous journeys in the Canadian Arctic, planned and led two large expeditions while associated with the Institute: the Arctic Institute Baffin Island expeditions of 1950 and 1953.

At a meeting of the Canadian Governors of the Institute held in Ottawa on 10 March 1954, the Assistant to the Director of the Montreal Office, Dr. Svenn Orvig, was appointed Director for the year beginning 1 July 1954.

Dr. Orvig was born in Bergen, Norway, and first visited Canada in 1937. During the war he served as a pilot with the Royal Air Force Ferry Command in Montreal, and with the Coastal Command in Iceland and the Shetland Islands. After the war he returned to Norway and studied meteorology, coming back to Canada in 1949 for postgraduate studies at McGill University. He obtained a M.Sc. degree in the Department of Geography in 1951, and the Ph.D. in 1954. For the past three years Dr. Orvig has been Assistant to the Director of the Montreal Office and a lecturer in the Department of Geography, McGill University. He was a member of both the Institute Baffin Island expeditions.

Award of Institute research grants

The following have been awarded grants, or otherwise sponsored, by the Institute for the 1954 season:

BURSA, ADAM S. 548 W. 113 St., New York, N.Y., U.S.A.

Studies of the annual cycle of phytoplankton production in the Arctic Ocean.

DEHNEL, PAUL A. Dept. of Zoology, University of California, Los Angeles, California, U.S.A.

Study of the productivity of organic matter in the sea as a function of latitude.

EDWARDS, ROBERT L. Waltham, Massachusetts, and CHAMBERLAIN, J. LOCKWOOD, Cambridge, Massachusetts, U.S.A.

Hydrographic and ecological studies of representative marine areas in James and Hudson bays.

ELLIS, D. V. McGill University, Montreal, Quebec, Canada.

Investigation of littoral and shallow water fauna of northwest Baffin Island.

ERICSON, DAVID B. Lamont Geological Observatory, Palisades, N.Y., U.S.A.

Studies of deep sea sediment cores from arctic and subarctic waters.

HANNA, G. DALLAS. Academy of Sciences, Golden Gate Park, San Francisco, California, U.S.A.

Investigation of the geology of the continental shelf in the vicinity of Point Barrow, Alaska.

MAZZEO, ROSARIO. Massachusetts Audubon Society, Boston, Massachusetts, U.S.A.

A study of the ornithology, botany, geology, and geomorphology of Bylot Island.

McBEE, RICHARD H. Botany and Bacteriology Department, Montana State College, Bozeman, Montana, U.S.A.

Study of thermophilic bacteria in arctic soils and waters.

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MOHR, JOHN L. Dept. of Zoology, University of Southern California, Los Angeles, California, U.S.A.

To continue the investigation of the ecology of arctic crustaceans.

NUTT, DAVID C. Dartmouth College, Hanover, New Hampshire, U.S.A.

Hydrobiological study in the coastal waters of Labrador using the facilities of the research vessel *Blue Dolphin*.

RAY, G. CARLETON. Zoology Dept., Columbia University, New York, N.Y., U.S.A.

An investigation of the effects of cold temperatures on the size of cold-blooded animals in reference to Bergmann's rule of size of species.

REX, ROBERT W. Scripps Institution of Oceanography, San Diego, California, U.S.A.

Oceanographic and limnological investigations at Point Barrow, Alaska.

SCHOLANDER, PER F. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.

An investigation of osmotic pressures in the blood of subarctic marine fishes.

SONNENFELD, JOSEPH. Bowman School of Geography, The Johns Hopkins University, Baltimore, Maryland, U.S.A.

Study of the changes in culture of Point Barrow Eskimo as a result of contact with local large scale modern enterprise.

STEERE, WILLIAM C. Dept. of Biological Sciences, Stanford University, Stanford, California, U.S.A.

Investigation of collected specimens in connection with bryological problems of arctic field work.

THOMPSON, DANIEL Q. Dept. of Zoology, University of Missouri, Columbia, Missouri, U.S.A.

To continue study of the ecology of the lemmings.

WIGGINS, IRA L. Natural History Museum, Stanford University, Stanford, California, U.S.A.

To complete analysis of field data collected at Point Barrow by comparison with specimens at herbaria.

WILCE, ROBERT T. Dept. of Botany, University of Michigan, Ann Arbor, Michigan, U.S.A.

Study of marine flora in the Strait of Belle Isle, Newfoundland.

WILIMOVSKY, NORMAN J. Natural History Museum, Stanford University, Stanford, California, U.S.A.

To determine the relative nutriment content of ice meltwaters in comparison with neighbouring open seas. *Also*: To continue the study of the fish fauna of arctic Alaska.

WOHLSCHLAG, DONALD E. Dept. of Biological Sciences, Stanford University, Stanford, California, U.S.A.

Investigation of the fishery resources in waters on the northern Arctic Slope, Barrow area.

McGill University–Arctic Institute Carnegie Program

The 1953–4 Carnegie Fellow, Dr. J. W. Wilson, spent the winter at McGill University and the Institute. He left for Resolute Bay, Cornwallis Island, on June 15 to study the physiological effects of "exposure" and of soil and water relations on plants under arctic conditions.

The 1954–5 Fellowship has been awarded to A. Bursa, who plans to study phytoplankton samples collected in Hudson Bay by the M.V. *Calanus*.

This summer six scholars will be doing field work in the north:

MARJORIE FINDLAY, Geography, U.K. Citizen: Fort Chimo.

MICHAEL MARSDEN, Geography, U.K. Citizen: Coppermine.

GEORGE FALCONER, Geography, U.K. Citizen: Coppermine.

CLAUDE DESGOFFE, Anthropology, French Citizen: Belcher Islands.

JORGEN MELDGAARD, Anthropology, Danish Citizen: Igloolik.

JOHN TANGERMAN, Geography, U.S. Citizen: Labrador.

Five scholarships have been awarded for the winter 1954–5 with summer field work in 1955:

FRITZ MÜLLER, Geography, Swiss Citizen.

FRANK COOK, Geography, Canadian Citizen.

G. POWER, Zoology, U.K. Citizen.

D. R. OLIVER, Zoology, Canadian Citizen.

A. W. MANSFIELD, Zoology, U.K. Citizen.

Scientific program at the Arctic Research Laboratory, Point Barrow, Alaska

As a result of negotiations with the United States Office of Naval Research, the Arctic Institute has assumed responsibility for the scientific program at the Arctic Research Laboratory, Point Barrow, Alaska. Basic research relating to problems affecting northern engineering, communications, public health, and other fields will be carried on under the guidance of a special committee of the Institute, and will be coordinated by Mr. Joseph T. Flakne.

Mr. Flakne, the former Chief of the Alaska Division, Office of Territories, Department of the Interior, has spent most of his adult life in the north. Born in Beltrami, Minnesota, he graduated from the University of Alaska in 1934. Formerly Director of the United States Employment Service for Alaska and Alaska Specialist for the War Manpower Commission, he served during the Second World War in the Alaskan Headquarters of the United States Army.

The Chairman of the Institute's Arctic Research Laboratory Committee is Dr. Hugh M. Raup. The committee includes:

Dr. C. Earle Albrecht, Rear Admiral L. O. Colbert, Dr. Henry B. Collins, Jr., Dr. John Field, Dr. John C. Reed, Rear Admiral Edward H. Smith, Dr. A. L. Washburn, Dr. Alexander Wetmore, Dr. Ira L. Wiggins, and Mr. Walter A. Wood.

Arctic session at the A.A.A.S. meeting in December

The Institute has accepted an invitation from the Western Society of Naturalists to join them in joint sponsorship of a program of papers in arctic science, with emphasis on biology, to be presented at the 121st meeting of the American Association for the Advancement of Science at the University of California, Berkeley, California, on 27, 28, and 29 December 1954.

Associates and Fellows of the Institute who wish to offer papers at this meeting should write to the Secretary of the Western Society of Naturalists, Dr. John L. Mohr, University of Southern California, Los Angeles 7, California, for details and "Call for paper" forms. Abstracts of papers should be in his hands by October 1. Papers are limited ordinarily to fifteen minutes reading time.

NORTHERN NEWS

Position of ice island T1

On the annual polar flights by the R.C.A.F. Specialist Navigation Course from the Central Navigation School a reconnaissance of ice island T1 was carried out.

On April 30 T1 was seen about seven miles north of Cape Stallworthy lying in an east–west direction with its wider end to the west; its size appeared to be

unchanged. T1 has therefore moved about 110 miles from its position in April 1953 at the entrance to Yelverton Bay as reported by the 1953 R.C.A.F. Specialist Navigation Course flights (see *Arctic*, Vol. 6, pp. 164–5).

No other ice islands were spotted although a lookout was maintained. T3 was flown over on the flight from the pole, but was hidden by low stratus.

The 1951 Census in the Northwest Territories[1]

The first official census in Canada was taken by Jean Talon, Intendant of New France, in 1666, and records a total of 3,215 persons. Subsequent censuses were taken at fairly frequent intervals, and the present decennial censuses date back to the passing of the British North America Act, which provided for the First Census of Canada to be taken in 1871. By this year the population had grown to 3,689,257 persons and in 1951 it had reached 14,009,429.

Figures for the population of the Northwest Territories, or, simply, "The Territories" as they were at first called, are given in all the decennial censuses, and a special census of Manitoba and the Northwest Territories was taken in 1886 ('Sixth Census of Canada, 1921', Vol. 1, p. ix). At that time the population figures for the more northerly areas were estimates only, and until 1912 the area of the Northwest Territories was considerably larger than it is today, at different periods including Alberta, Saskatchewan, and the Yukon, as well as parts of Quebec, Ontario, and Manitoba.

It was not until 1901 that the first enumeration of "the unorganized Territories of Keewatin, Athabasca, Mackenzie and Yukon was undertaken . . ." The 'Report on the Fourth Census of Canada, 1901', records that "For this service 110 enumerators were employed, with packers and canoemen to help in traversing the country, and wherever people were found—in mining camps, on fishing grounds, at trading posts or mission stations—a record of them by name was made in the usual way. But for greater convenience a special schedule with a limited number of inquiries was used for those Territories. The task was arduous and frequently perilous for the men who were engaged in it, but it is very gratifying to record that neither in those remote regions or elsewhere in the wide Dominion has the taking of the Census been attended with the loss of one life." (Vol. 1, 'Population', p. xiii).

[1]Reprinted from the *Arctic Circular*, Vol. 6 (1953) pp. 37–42.

The first figures for the Eskimo population are given in the Census of 1921. Previous to this time both Eskimo and Indians were classed as Indian. In 1921, 3,269 Eskimo were recorded, though a considerable proportion of the population must have been omitted.

The taking of decennial censuses involves a great deal of preparatory work, even in the settled parts of the provinces. In the Northwest Territories and in northern Quebec, the task is much more difficult because of the sparsity of the population, the distances to be covered, and the poor communications. In the District of Mackenzie, the arrangements for the 1951 Census were made by a Census Commissioner appointed at Yellowknife. He in turn appointed enumerators for each area. In other districts the Northern Administration and Lands Branch of the Department of Resources and Development cooperated with the Dominion Bureau of Statistics in appointing enumerators, in sending in the necessary supplies, and in collecting the completed returns. In many cases forms had to be sent in and all preparatory arrangements made a year in advance. The task of documenting a population with a density of only 0.01 per square mile spread over an area of $1\frac{1}{4}$ million square miles is extremely difficult. Yet all returns were completed and sent in to the Bureau of Statistics for tabulation by the autumn of 1951. The official 1951 figures for the population in the Northwest Territories are given at the end of this note, and the totals for the Yukon Territory are also included.

The accuracy of the Eskimo census has improved with each decade. In 1941 7,178 Eskimo were recorded[1], exclusive

[1]The 1941 and 1951 figures for the Eskimo population were prepared by the Department of Northern Affairs and National Resources and are the correct final figures. Slight discrepancies between these and the figures as published in the census reports are mainly due to duplication in the enumeration of Eskimo temporarily confined to hospitals in the provinces. In the 1941 Census the total Eskimo population is given as 7,205. The corresponding census figure for 1951, excluding Newfoundland-Labrador, is 8,646, and the total population 9,733.
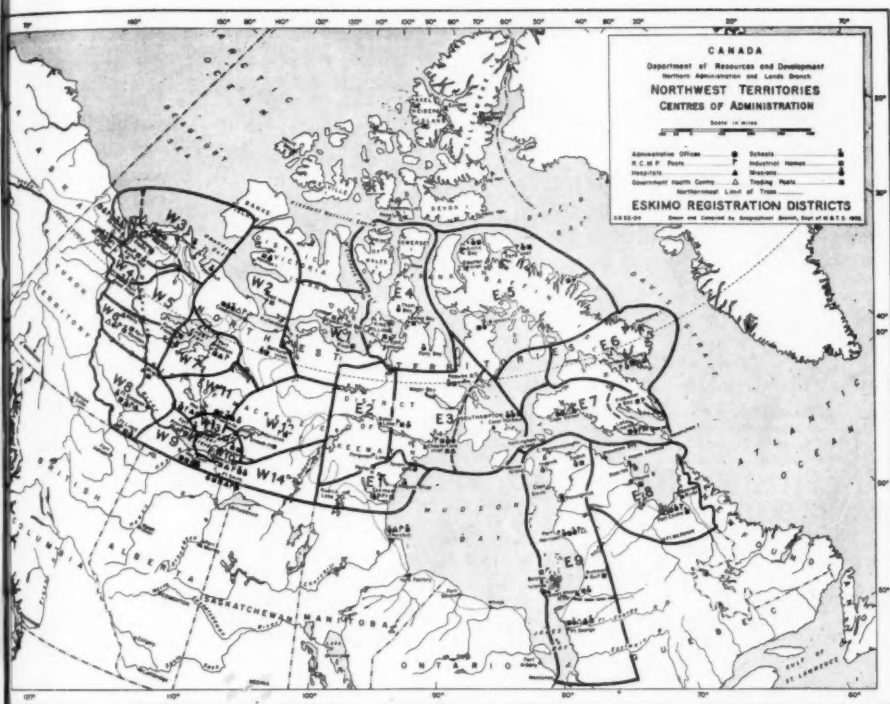
Fig. 1.

of Newfoundland-Labrador, which was not part of the Dominion at that time. In 1951 the total Eskimo population, if Newfoundland-Labrador is excluded, was 8,646. This increase of 1,468 in the population should probably be reduced by about 500, as a few isolated groups were known to have been omitted in 1941. With improved means of communication and the fullest cooperation from all organizations in the field, the 1951 figure is believed to be a very accurate record.

Comparisons between the 1941 and 1951 figures for the Eskimo population in the Cambridge Bay, Coppermine, and Pond Inlet districts are complicated by changes in the registration districts, made to agree with changes in the R.C.M.P. patrols. Since 1941 the Spence Bay district has been formed from areas previously included in the Cambridge Bay and Pond Inlet districts. In 1941 Bathurst

Inlet was included in the Cambridge Bay figures, in 1951 in the Coppermine, but since 1951 it has been returned to the Cambridge Bay district. The map shows the registration districts at the time of the 1951 Census.

The present Eskimo population is surprisingly youthful. Of the total of 9,493 in 1951, 2,018 were children 5 years of age and under, 1,141 were between 6 and 10 years of age, 1,163 were between 11 and 15, and 1,037 between 16 and 21 years of age. Less than 44 per cent of the total population was over 21 years old, as compared with a figure of 60 per cent for the whole of Canada. Only 483 Eskimo were over 55 years old.

It is reasonable to assume that, with greater security against want and steadily improving medical care, the increase in the Eskimo population will be maintained or accelerated in the next few decades.

TOTAL POPULATION — NORTHWEST TERRITORIES, 1951
(Figures based on the registration districts as shown on Fig. 1)

	Eskimo	Indians	Others	Total
Eskimo Point (E1)	446	–	38	484
Baker Lake (E2)	413	–	20	433
Chesterfield and Southampton Island (E3)	647	–	125	772
Spence Bay (E4)	462	–	19	481
Pond Inlet (E5)	908	–	32	940
Pangnirtung (E6)	591	–	17	608
Lake Harbour and Frobisher Bay (E7)	1,014	–	75	1,089
Fort Chimo (E8)	31	–	–	31
Port Harrison (E9)	330	–	2	332
Cambridge Bay (W1)	295	–	11	306
Coppermine (W2)	624	–	31	655
Aklavik (W3)	1,080	175	261	1,516
Arctic Red River (W4)	–	463	36	499
Fort Good Hope (W5)	–	257	28	285
Fort Norman (W6)	–	270	175	445
Port Radium (W7)	–	35	311	346
Fort Simpson (W8)	–	668	197	865
Fort Providence (W9)	–	470	688	1,158
Fort Resolution (W10)	–	277	336	613
Fort Rae (W11)	–	680	151	831
Reliance (W12)	–	62	8	70
Yellowknife (W13)	–	345	2,379	2,724
Fort Smith (W14)	–	101	341	442
Other Areas	16	–	63	79
TOTAL	6,857	3,803	5,344	16,004

TOTAL POPULATION — YUKON TERRITORY, 1951

Others	7,563
Indians	1,533
Total	9,096

ESKIMO CENSUS ONLY
(Figures based on the registration districts as shown on Fig. 1)

Northwest Territories	1941	1951
Eskimo Point (E1)	423	446
Baker Lake (E2)	267	413
Chesterfield (E3)	476	427
Southampton Island (E3)	136	220
Spence Bay (E4)		462
Pond Inlet (E5)	798	908
Pangnirtung (E6)	551	591
Lake Harbour (E7)	841	716
Frobisher Bay (E7)		298
Fort Chimo (E8)		31
Port Harrison (E9)		330
Other Areas (Craig Harbour)		16
Total — Eastern Arctic	3,492	4,858
Cambridge Bay (W1)	468	295
Coppermine (W2)	429	624
Aklavik (W3)	685	1,080
Total — Western Arctic	1,582	1,999
Total	5,074	6,857
Quebec		
Fort Chimo (E8)	615	627
Port Harrison and Moose Factory (E9)	1,489	1,162
Total	2,104	1,789
Labrador		
Total	not included	847
Total Eskimo population	7,178	9,493

Population of Eskimo peoples[1]

In the preceding note on "The 1951 Census in the Northwest Territories", figures are given for the Eskimo population in 1941 and 1951 in this area. The following table, which includes figures for Alaska[2], Greenland[3], and the Soviet Arctic[4], may therefore be of interest as it gives some idea of the Eskimo population, including Aleuts and Greenlanders, throughout the world.

	1926	1939	1941	1945	1950	1951
Alaska						
Aleut		5,599			3,892	
Eskimo		15,576			15,882	
Greenland						
Native population			19,360			22,890
Soviet Arctic						
Yuity (Eskimo)	1,293			1,300		
Canada			7,178			9,493[5]
Newfoundland-Labrador				701		

Comparative figures for the age groups of the Eskimo population are not readily available. In Alaska, in 1950, 54 per cent of the total native population (including Indians, Negroes, and Asiatics) was under 20 years of age, and in Greenland, in 1951, 36 per cent of the native population (Greenlander) was under 12 years of age, whereas in Canada, in 1951, 66 per cent of the Eskimo population was under 21 years, and 33 per cent was under 11 years of age.

Expeditions to north Ellesmere Island

During the summer of 1953 Geoffrey Hattersley-Smith of the Defence Research Board of Canada and R. G. Blackadar of the Geological Survey of Canada carried out glaciological and geological investigations in northern Ellesmere Island.

The party, with two Greenlanders and their dog teams, was flown in to Alert on April 21. May and the first part of June were spent travelling about

[1]Reprinted from the *Arctic Circular*, Vol. 6 (1953) p. 43.

[2]From the 'United States Census of Population, 1950', Vol. 2.

[3]From 'Report on Greenland, 1953', published by The Prime Minister's Second Department, Copenhagen, p. 2.

[4]From Webster, C. J. "The growth of the Soviet Arctic and Subarctic", *Arctic*, Vol. 4 (1951) p. 44.

[5]Including Labrador-Newfoundland.

900 miles by dog team along the Ellesmere Ice Shelf. On the first of their two journeys they reached as far west as Markham Bay. Stakes were set up along the ice shelf so that movement, surface wastage, and increment during the next year could be determined by the larger party planned for the summer of 1954, and observations were made of the extent and condition of the ice. Following these journeys the Greenlanders returned to Thule.

In July the party studied the ice cap and geology of the Unites States Range, covering about 350 miles on foot. They left Alert by aircraft on August 16.

An account of the geological results has been published by Blackadar.[1] Previous to this party no trained geologist had travelled along the north coast of Ellesmere Island, and all subsequent discussions were based on the paper written by Feilden and De Rance[2] from material collected by Feilden in 1875-6 on Nares's expedition.

Several significant facts emerge from the geological study made during the summer of 1953. First, the existence of highly metamorphosed strata and of granitic rocks on the northernmost coast of Ellesmere Island has definitely been established. Secondly, the possibility that there are many structural unconformities indicates that the geological evolution of the region was a complex one. An apparent unconformity between a fossiliferous Middle Silurian limestone and the Cape Rawson group suggests that the latter is either Middle Silurian or older. Another probable unconformity, in the Late Carboniferous or Early Permian rocks on Feilden Peninsula, points to a second orogeny in the region. Finally, a third orogeny is indicated between undisturbed Tertiary beds and the youngest Palaeozoic strata.

[1]Blackadar, R. G. 1954. 'Geological reconnaissance north coast of Ellesmere Island, Arctic Archipelago, Northwest Territories'. *Geol. Surv. Can. Paper* No. 53-10, 22 pp. and map.

[2]Feilden, H. W. and C. E. De Rance. 1878. "Geology of the coasts of the arctic lands visited by the late British expedition under Captain Sir George Nares, R.N." *Q. J. Geol. Soc. Lond.* Vol. 34, pp. 556-67.

On 24 April 1954 a joint Canadian/United States party led by Geoffrey Hattersley-Smith of the Defence Research Board of Canada was landed on the Ellesmere Ice Shelf by the U.S.A.F., three miles west of Ward Hunt Island. The members of the party are: R. L. Christie, Geological Survey of Canada, A. P. Crary, Geophysics Research Directorate of the U.S.A.F. Cambridge Research Center, and E. W. Marshall, Snow, Ice, and Permafrost Research Establishment of the U.S. Corps of Engineers. As in 1954, two Greenlanders and their dog teams were taken in from Thule to assist the party.

Request for arctic postal information

One of our Associates, Lieut. G. J. Raymond, U.S.A.F., is making a study of arctic postal history and postmarks. He is searching for envelopes from letters posted in the north, information on past, present, and proposed post offices, photographs of post offices and postmasters, and other related material for his reference collection. Offers of any of these items would be welcomed by Lieut. Raymond with gratitude and/or suitable remittance, according to the wishes of the sender. His address is 3715 Alberta Street, Houston 21, Texas, U.S.A.

OBITUARY

W. R. B. Battle (1919–1953)

On 13 July 1953 Ben Battle was accidentally drowned in Baffin Island while returning from a lone walk near the Base Camp of the Arctic Institute's 1953 expedition.

Walter Ravenhill Brown Battle was born on 23 December 1919 in Leeds, England, and educated at Leeds Grammar School, and at the University of Leeds, graduating in geography in 1949. Having registered as a conscientious objector he spent most of the duration of the war working on English farms. Ben was early interested in mountains and in climbing, and with this background it was natural that he should become a keen glaciologist. In 1948 and 1949 he went to east Greenland with the Danish Pearyland expeditions. Then from 1949 to 1953 he carried out research for a doctoral degree of the University of Cambridge, on the formation of corries. He tested the validity of the hypothesis that freeze-thaw action within a bergschrund results in corrie erosion by gradual shattering of the rock wall. During this time he took temperature recordings in bergschrunds in Norway and Switzerland, and made laboratory experiments, beam-testing rocks which had been exposed to alternate freezing and thawing.

In 1952 he was awarded the Senior McGill University–Arctic Institute Carnegie Fellowship, and he and his wife, Barbara, went to live in Montreal. He continued his studies on the Institute's 1953 Baffin Island expedition. His results indicate that it is unlikely that freeze-thaw action in bergschrunds can cause corrie formation. A number of his glaciological papers have been published in scientific journals. He firmly believed in the application of more experimental and quantitative research in geomorphology.

Ben was in many ways a man of unusual and firm ideals, many of them at variance with contemporary society, but springing from his deep humanism. Ever cheery and open hearted, he delighted in his fellow men, and so got on famously with them. To have him as a companion, in city life, in winter skiing, and on the Baffin expedition was a constant pleasure. For the writer it will always be a joy to relive these memories again.

ADAM WATSON